

Medium voltage products

Technical Application Papers No. 16

Electrical safety in medium voltage plants

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1. Introduction

Generally speaking, all energy sources are potentially dangerous, but an “acceptable safety level” (which will never be absolute) can be ensured by taking the appropriate precautions and using devices required by law and the standards or provided by technical development.

Electric energy is no exception. Designers of an electrical installation must therefore consider three criteria, in order of importance:

- safety of operators when using the electricity. Human life must be always safeguarded, regardless of the cost of the risk-reducing precautions and devices;
- functionality, meaning the ability of the installation to perform the tasks for which it was designed. When achieving this goal, it is also important to reduce the environmental impact with a view to contributing towards sustainable development;
- self-protection, which leads us to protect the electrical installation itself for the purpose of safeguarding our investment, thus to limit the effects of faults and to restore the installation to a fully functional condition within the shortest possible time.

Building safe electrical installations is by far the most important focus and various players and organizations contribute towards achieving this goal, i.e.:

- the national and European Parliaments that issue the laws;
- the authorities that develop domestic and international regulations and draw up technical standards;
- research organizations that study increasingly new and better techniques and systems.

The EU Directives and national legislation

One of the institutional tasks of the European Union is to issue directives, which must first be adopted by the Member States and then converted into national laws. Once transposed, these directives acquire legal validity and become a reference for constructors, installers and dealers who are obliged to comply with the obligations established by the laws.

The directives are based on the following principles:

- harmonization is limited to essential requirements;
- only products that conform to the essential requirements may be marketed and put into service;
- harmonized standards, the numbers of which are published in the Official Journal of the European Union and which are transposed into national laws, are considered as conforming to the corresponding essential requirements;
- application of harmonized standards or other technical specifications is discretionary and constructors are free to choose other technical solutions able to guarantee conformity to the essential requirements;
- constructors may choose from among the different conformity assessment procedures envisaged in the applicable directive.

The purpose of each directive is to ensure that constructors resort to expedients or measures able to prevent the product from jeopardizing the safety and health of persons, animals and things.



Technical specifications comprise the provisions according to which machines, apparatus, materials and installations must be designed, built and tested so that efficient and safe operation is ensured.

Technical specifications, issued by domestic and international bodies, are drawn up in detail and can acquire legal value when this is attributed by a legislative measure.

The scopes of application are Electrical Engineering and Mechanical Engineering, Ergonomics, Electronics, Telecommunications and Safety.

The bodies governing the electrical and electronic sector are IEC (International Electrotechnical Commission), the corresponding Italian CEI (Comitato Elettrotecnico Italiano) and CENELEC (European Committee for Electrotechnical Standardization).

The International Electrotechnical Commission (IEC) was officially founded in 1906 for the purpose of guaranteeing international cooperation with regard to standardizing and certification in the electrical and electronic sector.

The association is formed by the National Committees of over 60 different countries worldwide (full members). The IEC publishes international standards, technical guides and technical reports that form the basis, or are an important reference for all domestic and European standardizing activity. IEC standards are normally published in two languages: English and French.

1. Introduction

CENELEC was established in 1973.

It currently includes 32 member countries and cooperates with others, called affiliates (which first maintained their domestic documents together with those of CENELEC and then replaced them with the Harmonisation Documents HD).

The difference between European Standards (ENs) and Harmonisation Documents (HDs) lies in the fact that while the former must be transposed by countries in an identical way and without any additions or amendments, the latter can be amended to suit particular national requirements. Generally



speaking, EN Standards are published in three languages: English, French and German. In 1991, IEC and CENELEC signed cooperation agreements on common planning of new work and parallel voting on regulation projects. CENELEC deals with specific issues, for which standards are urgently needed. When research into a specific issue has already been begun by IEC, the European Standards Organization (CENELEC) can decide whether to accept or, where necessary, amend the work already approved by the International Commission.

In Italy, the standards are issued by the Comitato Elettrotecnico Italiano (CEI), which follows the directions of CENELEC.

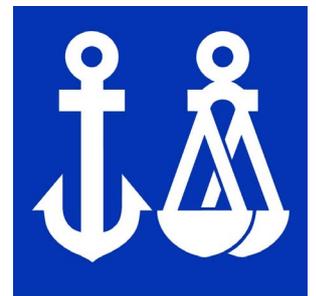
Shipping approvals must also be considered. The environmental conditions in which circuit-breakers installed on ships must operate may differ from the operating conditions on land. Application in a marine environment may mean the apparatus has to be installed in particular conditions, such as:

- high temperature and humidity levels, also in a saline atmosphere (hot-humid-saline environment);
- conditions on board ships (engine room) where equipment operates in the presence of incessant vibrations of significant amplitude.

In accordance with the shipping registers, such equipment must be subjected to specific type-approval tests to ensure it is able to function properly in such conditions. The most important of these tests include resistance to vibrations, dynamic stress, humidity, dry-heat.

The more important shipping registers include:

- RINA Registro Italiano Navale, Italian shipping register
- DNV Det Norske Veritas, Norwegian shipping register
- BV Bureau Veritas, French shipping register
- GL Germanischer Lloyd, German shipping register
- LRs Lloyd's Register of Shipping, UK shipping register
- ABS American Bureau of Shipping, USA shipping register



2. Standard and rules in the electrical/electronics sector

Law 1 March 1968, No. 186 “Provisions concerning the manufacture of electric and electronic materials, apparatus, machinery, installations and systems”, established two fundamental principles:

Art. 1. All electric and electronic materials, apparatus, machinery, installations and systems must be designed and built in accordance with the best working practices.

Art. 2. Electric and electronic materials, apparatus, machinery, installations and systems designed in compliance with the standards issued by the Italian Electrotechnical Committee are considered to be built in accordance with the best working practices.

Following this, pursuant to law 46/1990, the UNI standards also acquired Best Practices Recognition.

The legislator therefore delegates technical standardization to these bodies.

In addition, compliance with Legislative Decree 81/08, in the light of the new standard CEI 11-27:2014 and standard CEI 50110-1 EDITION III of 2014, must also be considered. Another of the standards to be considered is IEC EN 61482 part 1 and 2 “Live working – Protective clothing against the thermal hazards of an electric arc” when it comes to providing workers exposed to the hazards of an electric arc with personal protective equipment.

Generally speaking, according to Legislative Decree 81/08, designers, manufacturers, suppliers and installers must comply with the following obligations for all systems, apparatus and other technical equipment:

Art. 22. (Designers' obligations)

1. Designers of workplaces and workstations and systems shall comply with general prevention principles for workplace health and safety when they design projects and make technical decisions, and they shall also make use of protection devices, equipment and components that meet the essential safety requirements laid down in current the legislation and regulations.

Art. 23. (Manufacturers' and suppliers' obligations)

1. It is forbidden to manufacture, sell, rent and lease plants and personal protective equipment that fail to meet the current legislation and regulations governing health and safety at work.
2. If property liable to conformity certification procedures is leased, such property must be accompanied by the relative documentation, at the grantor's charge.

Art. 24. (Installers' obligations)

Installers and fitters of installations, work equipment or other technical equipment must, with regard to the part that falls within their competence, comply with the regulations relating to health and safety at work, and with the instructions provided by the respective manufacturers.

In the specific case of electrical hazards, Item III of Legislative Decree 81/08 “Electrical plant and equipment”, article 80 “Employer's obligations” describes the employer's obligations concerning the presence of electrical hazards in specific detail. More specifically, the aforementioned Legislative Decree explicitly establishes the obligation to take the necessary measures in order to protect workers from electrical hazards through use of electrical materials, apparatus and systems and, in particular, hazards deriving from:

- a) direct electric contacts;
- b) indirect electric contacts;
- c) ignition and propagation of fires and burns due to dangerous overtemperatures, electric arcs and radiations;
- d) ignition of explosions;
- e) direct and indirect electrocution;
- f) overvoltages;
- g) other reasonably foreseeable fault conditions.



Risk assessments must take account of three fundamental issues:

- a) the specific conditions and characteristics of the work, considering any interferences involved;
- b) the hazards in the workplace;
- c) all the foreseeable operating conditions.

The employer must then take all the necessary technical and organizational measures able to eliminate or reduce the risks present, identify the collective and personal protective equipment that ensures the work is performed in safe conditions and draw up operation and servicing procedures able to ensure that the level of safety achieved by implementing the safety measures is maintained over time.

Article 81 "Safety requirements" specifies that, without prejudice to the laws and regulations transposing the EC product-specific directives, the materials, machinery, apparatus, installations and plant referred to in the previous paragraph are considered to be built in accordance with the

best working practices when they are built in compliance with the pertinent technical standards.

One must also bear in mind that, in accordance with article 82 "Live working" it is forbidden to work on live apparatus except when the voltage is in conditions of safety or when the work is performed in accordance with certain conditions (among which, when the procedures adopted and equipment used conform to the criteria established in the technical standards).

For instance, live working is allowed for "category 0 and I systems (<1000V) so long as the work on live parts is performed by workers recognized by the employer as fit for such activities according to the indications in the pertinent technical regulations."

The majority of "medium voltage" installations and equipment come under category II: "with over 1000 V rated voltage if in alternating current or over 1500 V rated voltage if in direct current, up to 30,000 V inclusive"; "Category III (third) systems, also called high voltage systems, are those with over 30,000 V rated voltage. For the purpose of classifying a system, the rated voltage to earth is considered if this is higher than the rated line-to-line voltage. The term electrical system means the part of an electrical installation formed by a group of electrical components with a certain rated voltage." (Annex IX to Legislative Decree D.lgs.81/2008).

In addition, it is important to remember that the expertise of the persons who perform the work must also be assessed even in the case of non-live working, but in the vicinity of live parts. The legislator has also considered those who must perform generic jobs of a non-electrical type but in the presence of electrical hazards:

Art. 83. (Work near live parts)

1. Non-electrical work may not be performed near electric lines or electrical installations with unprotected live parts or when, in particular circumstances, they must be considered as being insufficiently protected and, in any case, at a shorter distance away than the limits established in table 1 of annex IX, unless organizational and procedural provisions able to protect the workers against the consequent risks are adopted.
2. The provisions in the pertinent technical standards are considered adequate for the purposes referred to in paragraph 1.



2. Standard and rules in the electrical/electronics sector

Thus, when electrical hazards are assessed, one must especially consider hazards that are not mitigated previously by design or construction according to best working practices, particularly electrical hazards relating to inadequate maintenance and inspection of the electrical installations and apparatuses or insufficient training of personnel.

Precise roles and responsibilities must be assigned to the personnel charged with performing electrical work, with organizational and supervisory tasks, work that must be performed in compliance with the regulations, i.e. with standard CEI 11-27:2014 "Work on electrical installations" and IEC EN 50110-1:2014 "Operation of electrical installations".

According to standard CEI 11-27, employers must assign the qualification to work on electrical installations in writing: this qualification can be "qualified/skilled person" (PES), "instructed/trained person" (PAV) and person "fit for live working" (PEI). Standard CEI 11-27 therefore contains both requirements and guidelines for the purpose of identifying the minimum requisites with regard to training, in terms of technical knowledge, organizational abilities and practical performance of electrical work.

The aforementioned standard does not apply to live working on installations with voltage ratings exceeding 1000 V in alternating current and 1500 V in direct current, which are covered in Standard CEI 11-15. From a regulatory aspect, in implementation of Legislative Decree D.lgs.81/2008, live working in the presence of voltage exceeding 1000 V is governed by Ministry of Health Decree of 4 February 2011, also known as "live working decree", which covers work in the presence of voltage exceeding 1000 V authorized by the Ministry of Labour. When it comes to medium voltage industrial applications, it is important to remember that this decree establishes that the following do not constitute "live working"

- a) operation of isolating, breaking and adjusting apparatus and fixed earthing and shorted devices, under normal operating conditions;
 - b) operation, by means of earthing sticks, of the aforementioned apparatus under normal operating conditions;
 - c) use of voltage detectors and comparators built and used under the conditions specified by the manufacturer or by the standards themselves;
 - d) use of insulating proximity detectors in the envisaged conditions of use;
 - e) washing of insulators by fixed automatic or remote controlled systems;
 - f) use of movable earthing and shorted devices;
- jobs in which work is performed on components that are part of machines or apparatus powered by voltage not exceeding 1000 V even though they operate at higher voltage.

2.1 Protections against electric shocks through direct or indirect contacts

Medium voltage protection against both direct contacts (i.e. when a person comes into contact with a conductor which is live under normal circumstances) and indirect contacts (i.e. when a person comes into contact with an exposed-conductive part which is not normally live, but has become live accidentally) can only be obtained by preventing the contact, thus the passage of current through the human body. To do this, fixed or movable protections with interlocks must be installed. In this case, the reference standard is IEC EN 61140 "Protection against electric shock - Common aspects for installations and equipment". The indications given must only be used if included in the specific product standards, but this standard is, however, of interest owing to the information it contains. The standard divides protections into basic protection, in normal operating conditions, thus against direct contacts, and fault protection, thus (generally) against indirect contacts.

In the former case, the live parts (i.e. live during ordinary service and therefore dangerous) must not be accessible. Vice versa, accessible conductive parts must not be dangerously live either in ordinary conditions or individual fault conditions. Thus basic protection must comprise one or more provisions which, in ordinary conditions, prevent contact with dangerous live parts. Such provisions include basic insulation, barriers or enclosures, obstacles and installation out of reach.

- Basic insulation: when solid insulation is used, it must prevent contact with dangerous live parts. If basic insulation is provided by air, access to dangerous live parts or entrance into a dangerous zone must be prevented by obstacles, barriers or enclosures or by installation out of reach.
- Barriers or enclosures: the barriers or enclosures must, in the case of low voltage installations and components, prevent access to dangerous live parts by providing a degree of protection against electrical contact of at least IPXXB (also provided by IP2X) of Standard IEC EN 60529. In the case of high voltage electrical installations and components, the barriers or enclosures must prevent entrance into a dangerous zone by providing a degree of protection of at least IPXXB (also provided by IP2X) of Standard IEC EN 60529. The barriers and enclosures must possess sufficient mechanical strength, stability and duration over time to preserve the required degree of protection, taking account of all the influencing conditions



to which it is forecast that such barriers and enclosures may be subjected both outside and inside the same. They must be securely fixed in place and, if the project or construction provides for removal of the barriers, this must only be possible by using a wrench or a tool.

- Obstacles: obstacles are designed to protect expert or instructed/trained persons, but are not designed to protect ordinary persons. When the electrical installation, system or components are operating in particular conditions (e.g.: live working, non-live working, work near live parts), obstacles must prevent, in the case of high voltage electrical installations and components, unintentional entrance into a dangerous zone. The obstacles can be removed without the use of a wrench or tool, but must be fastened in such a way as to ensure that their unintentional removal would be unlikely.

- Placing out of arm's reach: when the previous provisions cannot be applied, installation out of reach may be an appropriate measure for preventing, in the case of high voltage electrical installations and components, unintentional entrance into a dangerous zone.

The standard requires fault protection to include one or more measures that are independent from, and supplementary to those envisaged for basic protection. These are: supplementary insulation, protective equipotential bonding, protective screening, indication and interruption in high voltage installations and systems, automatic power outage, separation between circuits.

- Supplementary insulation: there is really not much to add, except that it must be sized to withstand the same stress described for the basic insulation.

2. Standard and rules in the electrical/electronics sector

- Protective equipotential bonding: in a high voltage installation or system, it must be earthed owing to the particular hazards that may be present, e.g. danger due to high contact and step voltage, and conductive parts that could become live after electric discharge. The impedance to earth of the earthing system must ensure that dangerous contact voltage does not occur. Conductive parts, which may become live in fault conditions, must be connected to the earthing system. Exposed conductive parts that could present dangerous contact voltage in the case of faulty basic protection, i.e. conductive parts and any protection screens, must be connected to the protective equipotential bonding system.
 - Protective screening: this must include a conductive screen installed between the dangerous live parts of an electrical installation, system or component and the part to be protected. The protective screen must be connected to the protective equipotential bonding system of the electrical installation, system or component.
 - Indication and disconnection in high voltage installations and systems: a device that signals faults must be installed. The fault current must be interrupted in the manual mode or automatically, depending on the neutral earthing system.
 - Automatic disconnection of supply: to achieve automatic power outage, there must be a protective equipotential bonding system, and a protection device activated by the fault current must, in the case of a basic insulation fault, interrupt one or more line conductors that feed the electric component, system or installation. The protection device can be installed in any suitable part of the electrical installation, system or component and must be chosen to suit the characteristics of the fault loop.
- Simple separation: simple separation between a circuit and the other circuits or earth must be created by means of basic insulation, which must be suitable for the highest voltage present, throughout the entire circuit.

Reference standards:

IEC EN 61140, (CEI 0-13 Classification): Protection against electric shock - Common aspects for installations and equipment

IEC EN 60529, (CEI 70-1 Classification): Protection class of enclosures (IP Code)

CEI 11-15;EC: Live working in category II and III electrical installations in alternating current

IEC EN 50110-1, (CEI 11-48 Classification): Operation of electrical installations, Part 1: General requirements

CEI 11-27: Works on electrical installations

CEI 11-81: Technical report: Guide to the innovations in the contents of Standard CEI 11-27, 4th edition, compared to the 3rd edition

2.2 Protection against high temperatures or ignition of potentially explosive atmospheres

The electrical system must be designed to ensure that, during normal operation, persons are at no risk of burns. For this reason, the standards prescribe the maximum temperatures that can be reached by accessible parts. In addition, the risk of igniting explosions or fire outbreaks owing to high temperatures or electric discharge must be reduced to the minimum. There are many different reference standards, depending on the type of explosive material and solutions envisaged.

Reference standards:

- IEC EN 62271-1, (CEI 17-112 Classification): High voltage switchgear and controlgear, Part 1: General specifications
- CEI 31-35: Explosive gas atmospheres - Guidance for the classification of areas with explosion hazards owing to the presence of gas in application of Standard IEC EN 60079-10-1 (CEI 31-87)
- CEI 31-35/A: Explosive gas atmospheres - Guidance for the classification of areas with explosion hazards owing to the presence of gas in application of Standard IEC EN 60079-10-1 (CEI 31-87) application examples
- CEI 31-56; V1: Explosive atmospheres - Guidance for the classification of areas with explosion hazards owing to the presence of combustible dust in application of Standard IEC EN 60079-10-2 (CEI 31-88)
- IEC EN 50495, (CEI 31-94 Classification): Safety devices required for the safe functioning of equipment with respect to explosion risks
- CEI 31-25; Ab: Areas at risk of explosion - Guidance for the construction and use of pressurized rooms or buildings in Class 1 areas
- CEI 31-26; Ab: Guidance for the maintenance of electrical constructions used in areas at risk of explosion in Class 1 and 3 (other than mines)
- IEC EN 60079-1, (CEI 31-58 Classification): Explosive atmospheres Part 1: Equipment protection by flameproof (explosion-proof) enclosures "d"
- CEI 31-56: Explosive atmospheres - Guidance for the classification of areas with explosion hazards owing to the presence of combustible dust in application of Standard IEC EN 60079-10-2 (CEI 31-88)
- CEI 64-2: Electrical installations in areas at risk of explosion, Specific requirements for the presence of inflammable dust and explosive substances
- IEC EN 60695-1-10, (CEI 89-30 Classification): Fire hazard testing, Part 1-10: Guidance for assessing the fire hazard of electrotechnical products - General guidelines
- IEC EN 60695-1-11, (CEI 89-31 Classification): Fire hazard testing, Part 1-11: Guidance for assessing the fire hazard of electrotechnical products - Fire hazard assessment

2. Standard and rules in the electrical/electronics sector

2.3 Protections against overvoltages and electromagnetic effects

Persons must be protected against overvoltage of both atmospheric origin and due to the operation of apparatus. They must also be protected against drops in voltage and its subsequent restoration. The installation must also be immune from electromagnetic phenomena and its emissions must be guaranteed as compatible with the operation of the devices installed, or connected to it.

Reference standards:

IEC EN 62561-1, (CEI 81-24 Classification): Lightning protection system components, Part 1: Requirements for connection components

IEC EN 60099-5, (CEI 37-3 Classification): Surge arresters, Part 5: Selection and application recommendations

IEC 61000-5-1: Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication

IEC 61000-5-2: Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling

IEC EN 61000-6-4, (CEI 210-66 Classification): Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments.

2.4 Protection against power cuts

Appropriate measures must be taken in the installation or in the devices installed when dangerous situations concerning power cuts are expected.

Reference standards:

CEI 11-20: Electric power generating plants and uninterruptible power sources connected to category I and II networks



2.5 Protection against discharge that could cause dazzling, excessive pressure and/or toxic gases

In this case, internal arc-resistant medium voltage switchgear has been developed that is able to protect persons by exhausting the pressure and gas in a non-dangerous way. Other, more sophisticated systems have been developed for the purpose of reducing the entity and arcing time of internal arcs, thereby limiting their effect.

Reference standards:

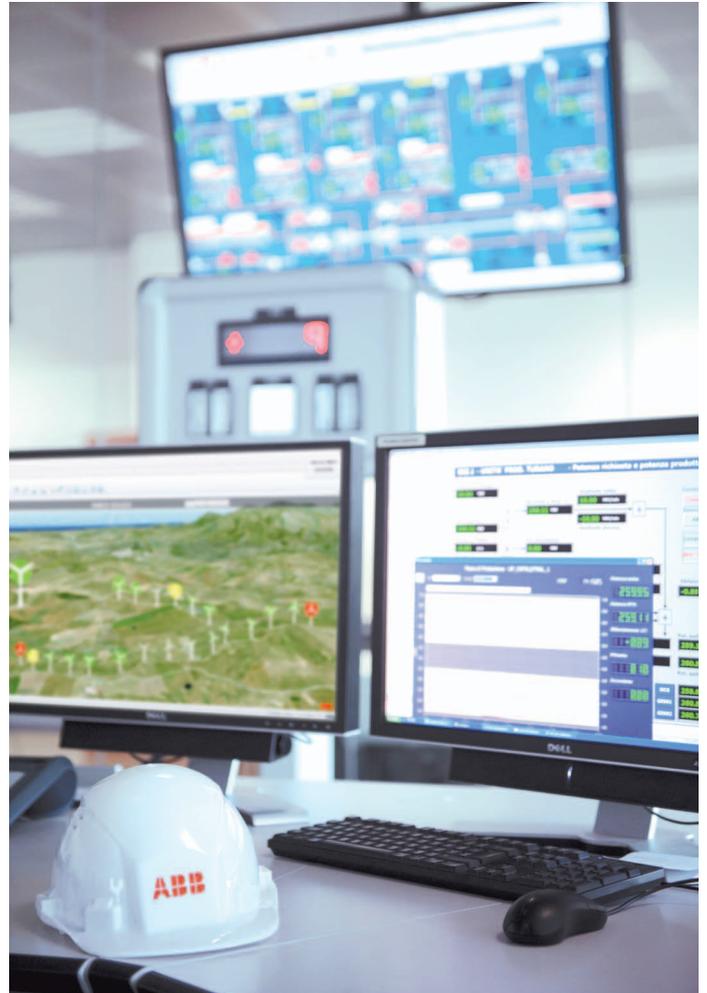
IEC EN 62271-200, (CEI 17-6 Classification): High voltage switchgear and controlgear, Part 200: Metal-enclosed factory-built switchgear and controlgear for rated voltages above 1 kV up to and including 52 kV

2.6 Protection against mechanical movements by electrically operated equipment

If dangerous situations caused by the movement of electrical equipment are expected, persons must be protected by erecting suitable barriers or by using safety interlocks.

Reference standards:

UNI EN 292: Safety of machinery - Basic concepts, general principles for design - technical principles and specifications



As already mentioned, correct servicing is required if an electrical installation is to remain efficient and if a high level of safety is to be maintained. The responsibility for this lies with the user, but remote monitoring and control systems can facilitate the task to a considerable extent. For MV/LV substations, reference should be made to standard CEI 0-15.

Reference standards:

CEI 0-15: Maintenance of the MV/LV substations of customers/end users

3. Electrical safety in medium voltage apparatus

3.1 Introduction



The product Standard for medium voltage circuit-breakers is IEC EN 62271-100 2010-09, "High voltage switchgear and controlgear, Part 100: Alternating current circuit-breakers". This standard is used in conjunction with Standard IEC EN 62271-1:2010-02, "High voltage switchgear and controlgear, Part 1: General specifications".

The standard applies to alternating current circuit-breakers designed for indoor or outdoor installation and for operating at 50 Hz and 60 Hz frequencies in systems with voltage exceeding 1000 V.

More specifically, it applies to three-pole circuit-breakers designed to operate in three-phase systems, single-pole circuit-breakers designed to operate in single-phase systems as well as the operating devices of these circuit-breakers and their auxiliary devices.

With regard to safety, the standard prescribes that possible chemical substances potentially harmful for the environment should be indicated and that pressurized vessels must be designed and tested in accordance with the standard itself. In addition, the apparatuses must be equipped with adequate interlocks (indicated as the most reasonable system for avoiding human errors), while critical operations from the aspect of safety must be clearly indicated in the instruction manual so as to avoid the consequences of inappropriate operations.

In the case of SF6 gas (sulphur hexafluoride) circuit-breakers and switch-disconnectors, ABB indicates, in the instruction manual, the presence of this gas, the environmental impact if it is accidentally dispersed and also states that any direct action involving the gas must be performed by ABB or by duly trained and competent personnel.



3.2 Interlocks

Even though it is not a true interlock, the anti-pumping device is still a safety system that prevents the operator from performing critical operations. According to the definition given by the standard, it is a device that prevents auto-reclosing after a closing-opening operation for as long as the closing command remains active. This prevents a continuous sequence of opening and closing commands from being given by mistake.

In the case of ABB vacuum or SF6 circuit-breakers, interlocks are more or less a consequence of the relation between the assemblies of the switchgear unit or the relation between different functional units.

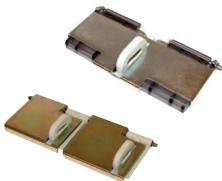
However, the apparatuses be provisioned to allow for these interlocks to be created.



For example:



Protection of opening and closing pushbuttons: the opening and closing pushbuttons can only be used by means of a dedicated tool.



Padlock holder for opening and closing pushbuttons: this device can hold one or more padlocks (up to three) so as to lock the opening and closing pushbuttons.



Key lock for holding in the open position: several options are available, such as different keys to lock the same circuit-breaker or the same key for different circuit-breakers. When the lock is applied, the opening pushbutton remains depressed, thus preventing local and remote closing of the circuit-breaker.



Locking magnet on closing mechanism: mechanically inhibits circuit-breaker closing if de-energized



Locking magnet on truck: prevents the circuit-breaker from being racked into the switchgear if the auxiliary circuit socket is disconnected. Since the socket can be equipped with a racking-in lock for different rated current values, the locking magnet indirectly prevents circuit-breakers with lower rated current values than those envisaged in the functional unit from being racked in.

This list is not exhaustive. Moreover, other interlocks are an intrinsic part of the circuit-breaker, as in the case of the anti-pumping device, and the interlock that prevents a withdrawable circuit-breaker from being connected or isolated when closed and from closing in the intermediate positions.

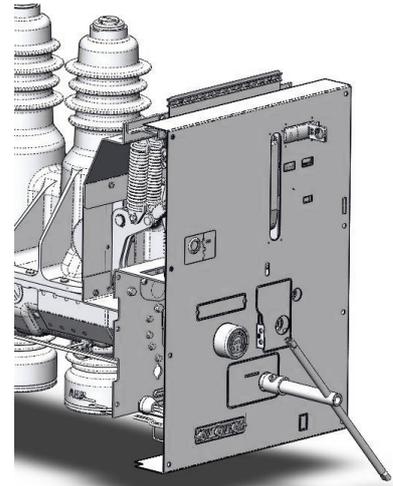
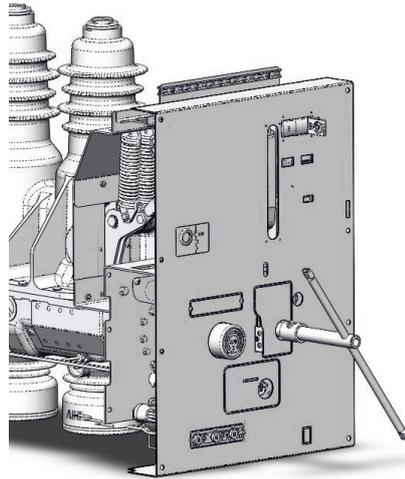
The situation changes for multi-function apparatuses that combine the functions of circuit-breaker, switch-disconnector and earthing switch, since the interlocks are more complex. This is the case of ABB's HySec apparatus, which is a compact multifunction apparatus.

3. Electrical safety in medium voltage apparatus

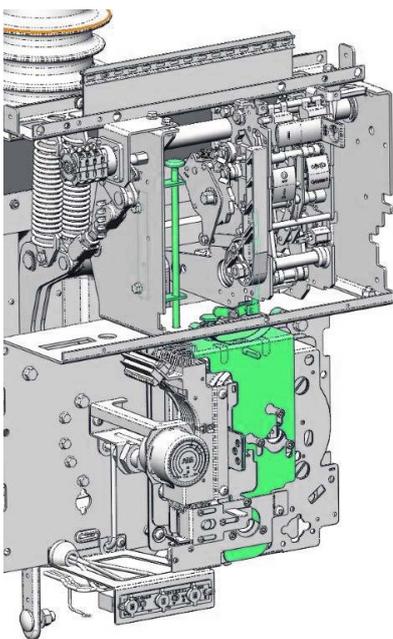
HySec is supplied with all the factory-tested interlocks among the different functions, i.e.:



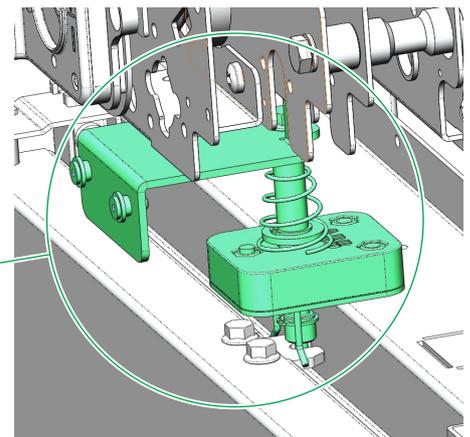
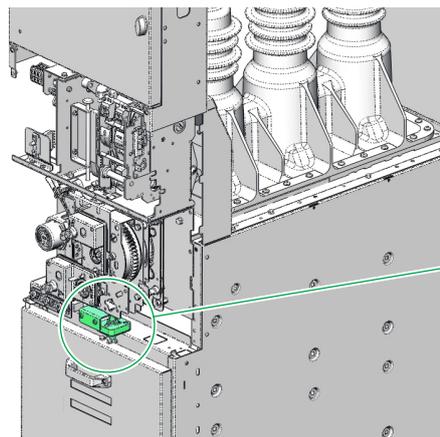
- Interlock between the feeder disconnecter and earthing switch using two different, interlocked connection points



- Mechanical interlocks between the circuit-breaker function, line switch-disconnector function and earthing switch



- Provision for an interlock between the earthing switch and the connection compartment door of the switchgear's functional unit (always installed in case of UniSec HBC unit)



- Specially shaped lock which prevents the operating lever from being left in its slot



- Key locks for locking the feeder disconnector and earthing switch in the open or closed positions (this accessory is an option when required for specific procedures).

Both GSec and HySec must also comply with the standard governing current disconnectors and earthing switches, i.e. IEC EN 62271-102, (CEI:17-83 Classification), "High voltage switchgear and controlgear, Part 102: Alternating current disconnectors and earthing switches" and with the one on switch-disconnectors, IEC EN 62271-103, (CEI:17-130 Classification), "High voltage switchgear and controlgear, Part 103: Switches and switch-disconnectors for rated voltages above 1 kV up to and including 52 kV".



With regard to the classification established by the standard for partitions and shutters, the qualifying and exclusive characteristic of both HySec and switch-disconnector GSec is their PM-class lower metal half-casing. This means that these two apparatuses can be used to create class LSC2 or LSC2A panels (as described in the next chapter) offering maximum flexibility in case of maintenance.

4. Electrical safety in medium voltage switchgear

4.1 Introduction

The product Standard for Medium Voltage switchgear is IEC EN 62271-200:2013-07, “High voltage switchgear and controlgear. Part 200: Metal-enclosed factory-built switchgear and controlgear for rated voltages above 1 kV up to and including 52 kV”.

This standard is used in conjunction with Standard IEC EN 62271-1:2010-02, “High voltage switchgear and controlgear, Part 1: General specifications”.

The previously mentioned enclosures can include fixed and removable components housed in compartments that can also be filled with fluid (liquid or gas) to provide insulation.

The standard establishes many different categories of equipment with metal enclosures that differ in:

- the effects on continuity of service in the network when the equipment is serviced;
- the need for servicing the equipment and the ease with which maintenance can be performed.



4.2. Definitions

Here are some of the definitions in the standard:

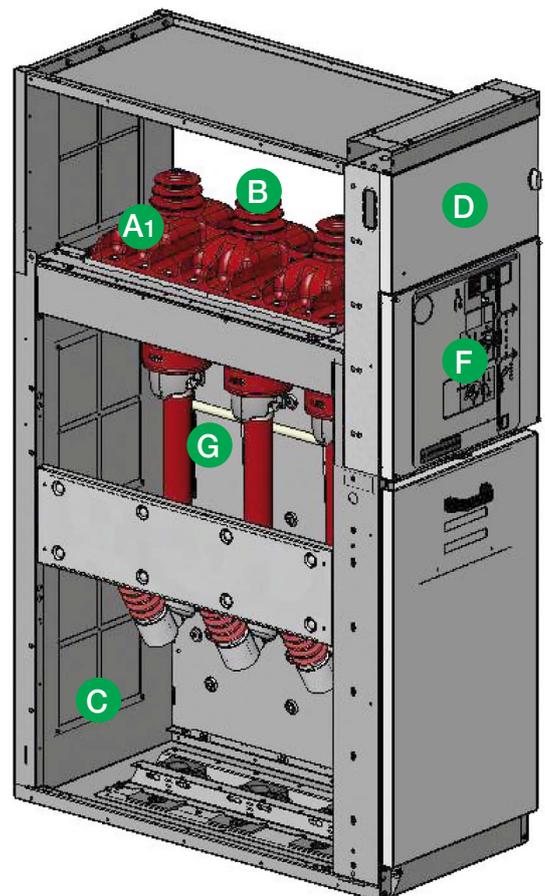
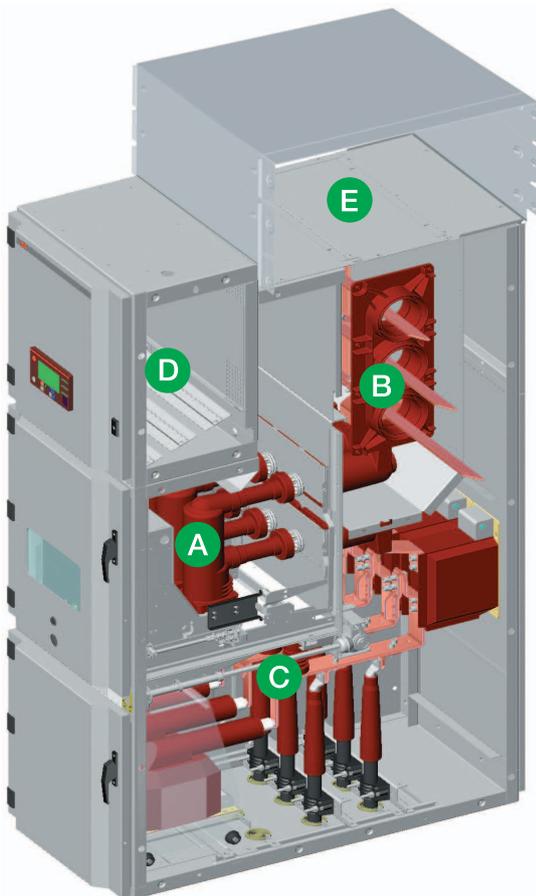
- **metal-enclosed switchgear and controlgear**
switchgear and controlgear assemblies with an external metal enclosure intended to be earthed and completely assembled, except for external connections
- **functional unit**
part of metal-enclosed switchgear and controlgear comprising all the components of the main circuits and auxiliary circuits that contribute to the fulfilment of a specific function. Functional units may be distinguished according to the function for which they are intended, for example: incoming unit, outgoing unit, etc.
- **enclosure**
part of metal-enclosed switchgear and controlgear providing a specified degree of protection of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts
- **high voltage compartment**
metal-enclosed switchgear and controlgear compartment containing high voltage parts, enclosed except for openings necessary for interconnection, control or ventilation. Four types of compartments are distinguished, three that can be opened, called accessible, and one that cannot be opened, called non-accessible
- **interlock-controlled accessible compartment**
compartment containing high voltage parts, intended to be opened for normal operation and/or normal maintenance as stated by the manufacturer, in which access is controlled by integral design of the switchgear and controlgear
- **procedure-based accessible compartment**
compartment containing high voltage parts, intended to be opened for normal operation and/or normal maintenance as stated by the manufacturer, in which access is controlled by a suitable procedure combined with locking
- **tool-based accessible compartment**
compartment containing high voltage parts, that may be opened, but not for normal operation and maintenance. Tools are necessary for opening
- **non-accessible compartment**
high voltage compartment that must not be opened
- **connection compartment**
high voltage compartment in which electrical connections are made between the main circuit of the switchgear and controlgear assemblies and the external conductors (cables or busbars) towards the network or the high voltage switchgear and controlgear of the installation

The first two types of accessible high voltage compartment are available to the user and are provided for normal operation and maintenance. Corresponding covers and/or doors of these two types of accessible compartments do not require tools for opening.

If a high voltage compartment requires tools for opening, then this is normally a clear indication that the users should take other measures to ensure safety and possibly to ensure performance integrity, for example, insulating conditions, etc. Lastly, in the case of non-accessible compartments, no user access is provided and opening may destroy the integrity of the compartment.

This must be signalled by a clear “do not open” indication on the compartment. In some cases, non-accessibility is clearly determined by the construction design, e.g. a completely welded GIS (Gas Insulated switchgear) tank.

Two examples of functional units are given below. The first is an outgoing functional unit with UniGear 550 switchgear circuit-breaker for primary distribution, while the second is an outgoing functional unit with UniSec switchgear switch-disconnector and fuses for secondary distribution. The different compartments can be distinguished in the two examples.



- A Circuit-breaker compartment
- A1 Switch-disconnector compartment
- B Busbar compartment
- C Cable compartment

- D Low voltage compartment
- E Gas exhaust compartment
- F Operating mechanism compartment
- G Fuse compartment

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4.3 Interlocks

Allowing user access during normal operation is an enormous responsibility which, in the case of interlocking devices, lies with manufacturers of switchgear and controlgear. On the other hand, the purpose is to ensure a high level of safety for operators who must perform their tasks during the normal operation of the installation. Standard IEC EN 62271-200 requires provision for interlocks whenever there are operations that put safety at risk or even to simply make the switchgear and controlgear easier to use. These devices must also be sufficiently sturdy to withstand attempted incorrect operations without damage.

In the case of main circuits, racking-in and racking-out circuit-breakers, switch-disconnectors or contactors must only be possible when they are in the open position. Their operation must only be possible when they are in the connected, isolated, withdrawn, test or earthing positions, but never in intermediate positions. Lastly, the interlock must prevent closing in the service position if these apparatuses are not connected to the auxiliary circuits associated with automatic opening or the apparatus itself. Vice versa, the interlock must prevent the auxiliary circuits from disconnecting when the circuit-breaker is closed in the service position.

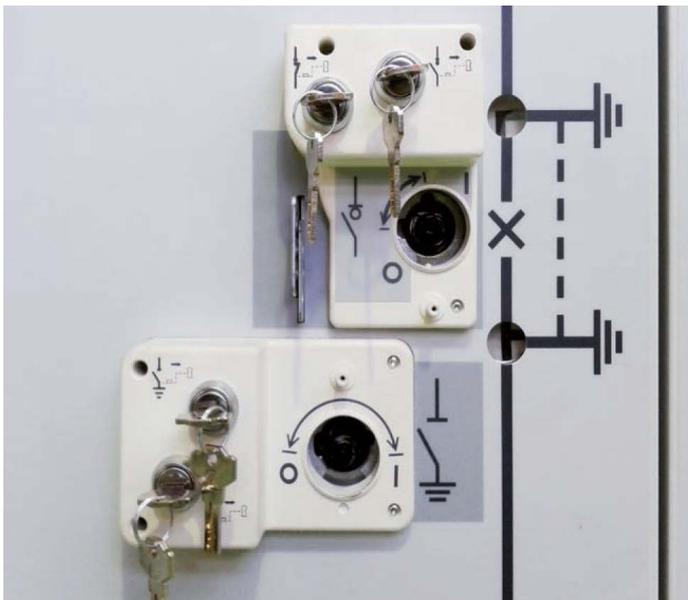
Make sure that disconnectors operate in the conditions for which they were designed. This means that the disconnector may only operate when the associated circuit-breaker or contactor is open.

Since the short-circuit making capacity of earthing switches is less than the admissible rated peak current value of the circuit, they should be interlocked with the associated disconnectors.

The photo alongside shows the interlock of functional unit SBC in UniSec switchgear between the earthed switch-disconnector and the earthing switch. The circuit-breaker compartment door is mechanically interlocked with the position of the earthing switches so as to ensure maximum safety conditions for operators who must work inside.

Apparatus installed in main circuits, faulty operation of which can cause damage or which are used for securing isolating distances during maintenance work, shall be provided with locking facilities (e.g. provision of padlocks) (provision for a UniSec switchgear padlock is shown in the photo).

If earthing of a circuit is provided by the main switching device (circuit-breaker, switch-disconnector or contactor) in series with an earthing switch, the earthing switch shall be interlocked with the main switching device.

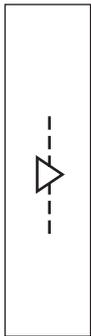


If non-mechanical interlocks are provided, the design shall be such that no improper situations may occur if the auxiliary supply is absent.

The following is a list of the interlocks provisioned in UniGear ZS1 switchgear. Some are provisioned by the standard and are therefore mandatory while others, such as the key interlocks on different functional units, depend on installation requirements.



Types of interlocks



Standard safety interlocks (mandatory)

Type	Description	Required condition
1	A Apparatus racking-in/out	Apparatus in "open" position
	B Closing of apparatus	Truck in defined position
2	A Apparatus racking-in	Multi-contact plug of racked-in apparatuses
	B Removal of multi-contact plug of apparatuses	Truck in test position
3	A Closing of earthing switch	Truck in test position
	B Apparatus racking-in	Earthing switch in "open" position
4	A Opening of apparatus compartment door	Truck in test position
	B Apparatus racking-in	Apparatus compartment door closed
5	A Opening of line compartment door	Earthing switch in "ON" position
	B Opening of earthing switch	Line compartment door closed

Note: The apparatuses are circuit-breakers and contactors.



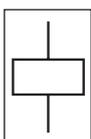
Keys (on request)

6	Locking of apparatus racking-in	Key can only be removed if truck is in "withdrawn" position
7	Locking of earthing switch closing	Key can only be removed if earthing switch is open
8	Locking of earthing switch opening	Key can only be removed if earthing switch is closed
9	Insertion of racking in-out lever of apparatuses	Key can always be removed
10	Insertion of earthing switch operating lever	Key can always be removed



Padlocks

11	Opening of apparatus compartment door	
12	Opening of line compartment door	
13	Insertion of racking in-out lever of apparatuses	
14	Insertion of earthing switch operating lever	
15	Opening or closing of shutters	



Locking magnets (on request)

16	Apparatus racking-in/out	Magnet live
17	Opening/closing of earthing switch	Magnet live

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Lastly, the manufacturer must provide full information about the purpose and operating mode of the interlocking devices. The standard requires a series of demanding tests for interlocks, for the purpose of highlighting design defects and to check whether these can be overcome:

- 25 attempts to open any interlocked door or covering;
- 50 attempts to access or use the operating interface, when access or use is prevented by an interlocking device (shutter, selector lever, etc.);
- 50 attempts to operate the switching devices in the manual mode, when the operating interface is accessible;
- 10 attempts to manually operate the switching device in the wrong direction must be performed in addition to, and in any point of the sequence of 50 attempts described above;
- 25 attempts to insert and 25 attempts to withdraw the removable parts.

The normal, manual crank handle operating mechanism must be used to perform these tests.

The normally used operating forces must be doubled during the tests.

Since interlock design-engineering, testing and operation are of critical importance, it is essential to rely on qualified manufacturers and, as far as possible, on factory-tested equipment.

4.4 Partitions and shutters

The standard makes a distinction between partitions (part that separates a compartment from the adjacent ones) and shutters (part that can be moved from a position where it permits contacts, e.g. of a circuit-breaker, to engage fixed contacts, to a position where it becomes part of the enclosure or partition shielding the fixed contacts). It therefore defines two classes, depending on whether the switchgear/controlgear has metallic partitions and/or shutters intended to be earthed, class PM, or has insulating partitions and/or shutters, class PI.





Class PM is the best choice for the safety of personnel working in the compartment, since it ensures that the structure is homogeneously earthed. The photograph illustrates the PowerCube solution showing metallic shutters, closed when the circuit-breaker is withdrawn and connected to the structure of the circuit-breaker compartment.

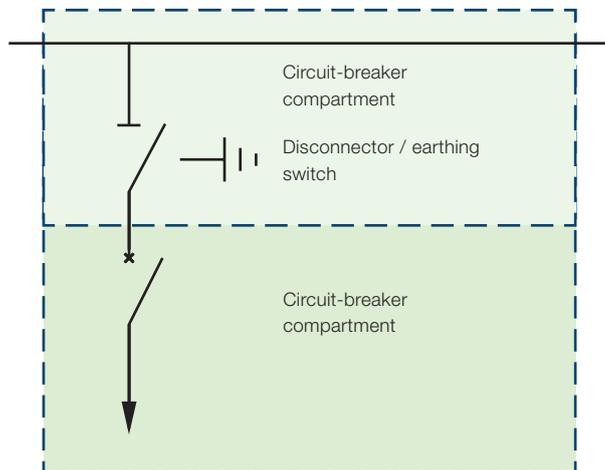
4.5 LSC categories

The standard also defines the performance the functional units must provide by introducing the Loss of Service Continuity concept (LSC). It establishes four main categories defining the extent to which other compartments and/or functional units may remain energized when an accessible high voltage compartment is opened. Generally speaking, designers can adopt different LSC categories for different loads and, thus, functional units. For this reason, the Standard requires LSC classification as a mandatory rating plate data item.



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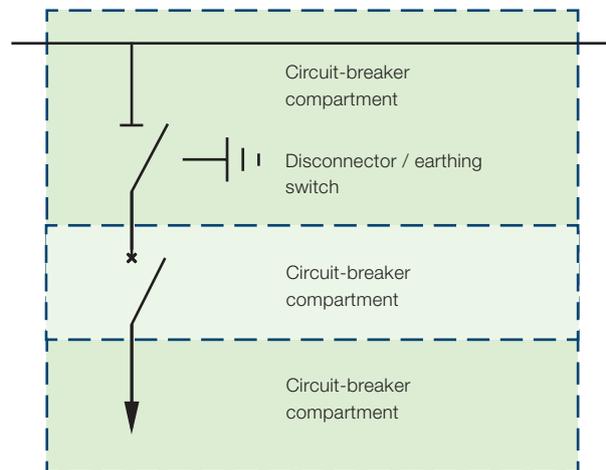
The four LSC categories envisaged by the standard will now be analyzed in detail: LSC2, LSC2A, LSC2B and LSC1.



- LSC2 category functional unit

This form is intended to allow maximum continuity of service of the network during access to the high voltage compartments inside the switchgear and controlgear. This means that the accessible high voltage compartments in a functional unit can be opened while the other functional units in the same section remain energized. It implies that at least one busbar must be kept energized. Installation of a removable partition can be used to obtain this category. Category LSC2 requires that at least the connection compartment may be opened while keeping the busbar(s) energized.

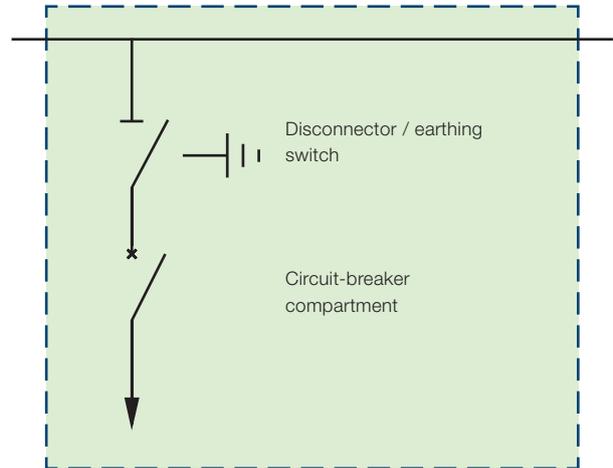
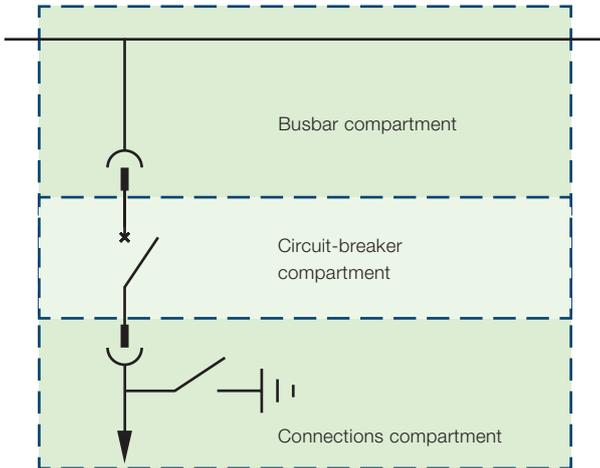
The standard defines two further categories (LSC2A and LSC2B) when LSC2 functional units have different accessible compartments (or apparatus) from the connections compartment.



- LSC2A category functional unit

The category LSC2 functional unit such that, when an accessible compartment (other than the busbar compartment of switchgear or controlgear with one single busbar) is open, at least one busbar may be kept energized and all the other functional units of the switchgear/controlgear may be kept in service.

In the example above, the disconnecter is installed in the busbar compartment and there is complete segregation between the busbar compartment and the circuit-breaker compartment. Both the circuit-breaker compartment and the connections compartment can be opened safely with the busbar live after disconnecter opening and closing of the earthing switch. The cables must be de-energized and earthed in order to access the circuit-breaker compartment.



- LSC2B category functional unit

This functional unit also corresponds to that of category LSC2, with the addition of other accessible compartments (or apparatuses). In addition to level of service continuity LSCA, the incoming high voltage connections (thus also the cable connections) to the functional unit may be kept energized when any other accessible high voltage compartment of the corresponding functional unit is open.

The example above includes withdrawable switching devices. If the main switching device of each LSC2B switchgear and controlgear is fitted in its own accessible compartment, maintenance may be performed on this main switching device without de-energizing the corresponding cable connection. As a consequence, a minimum of three compartments for each functional unit is necessary in this example of LSC2B switchgear and controlgear:

- for the main switching device;
- for connection compartment
- for busbar compartment. Where more than one set of busbars is provided, each set must be in a separate compartment.

- LSC1 category functional unit

Functional unit with one or more accessible high voltage compartments such that, when any one of these accessible high voltage compartments is open, at least one other functional unit may not be kept energized.

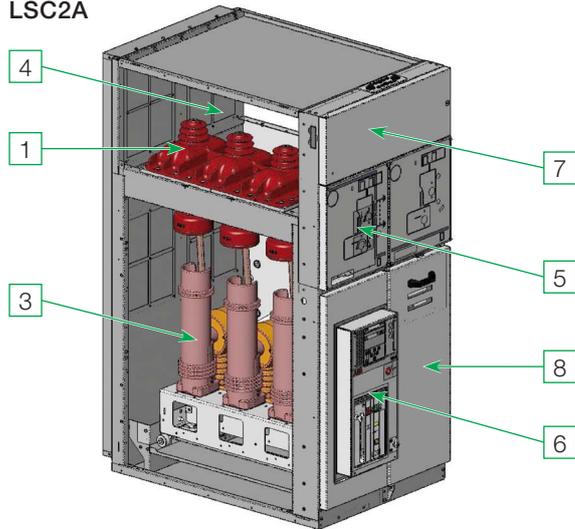
The example above illustrates a functional unit of a circuit-breaker with cable connections in the same compartment as the circuit-breaker and busbar, which will therefore be classified as LSC1.

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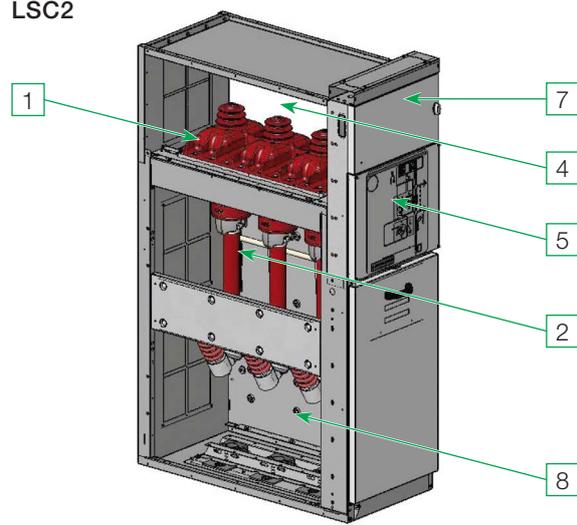
The next figures illustrate 3 functional units in UniSec switchgear, all with high categories (LSC2, LSC2A and LSC2B), thus able to ensure maximum continuity of service but with the degree of accessibility required for maintenance

and servicing work: SBC (circuit-breaker with switch-disconnector), SFC (switch-disconnector with fuses), WBC (unit with withdrawable circuit-breaker) and HBC.

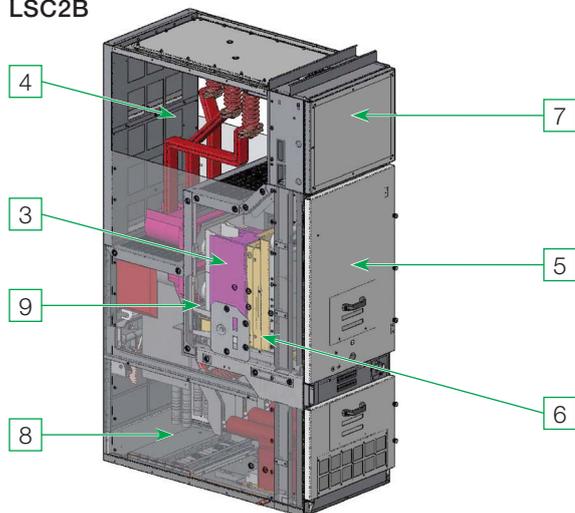
LSC2A



LSC2



LSC2B



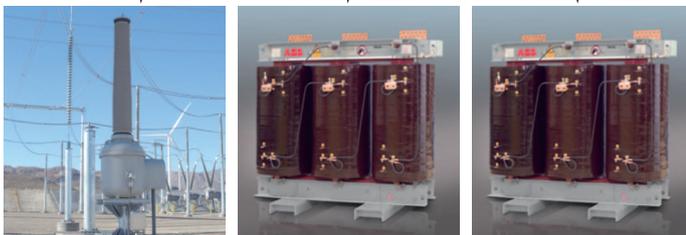
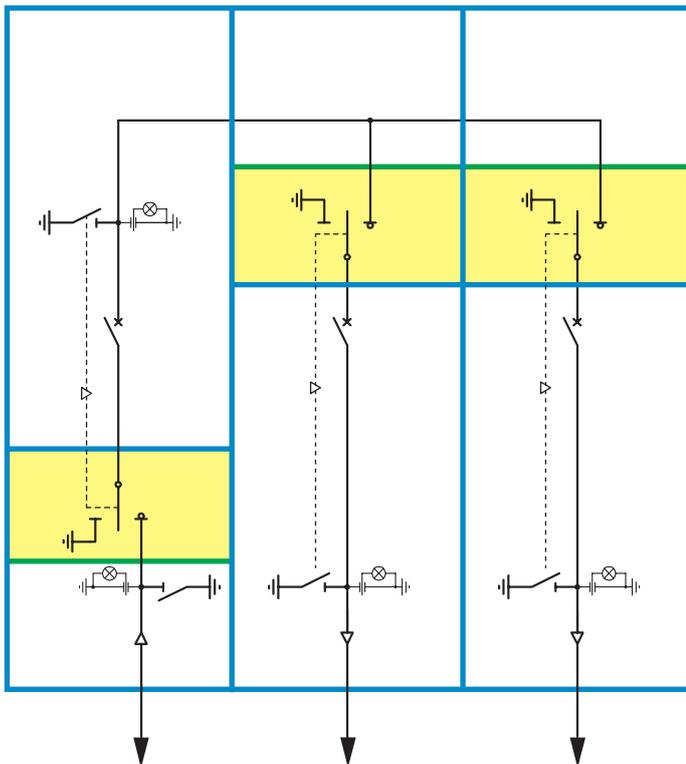
- 1 - Switch-disconnector
- 2 - Fuses
- 3 - Circuit-breaker
- 4 - Busbar compartment
- 5 - Operating mechanism compartment
- 6 - Circuit-breaker operating mechanism
- 7 - LV compartment for auxiliary circuits
- 8 - Cable compartment
- 9 - Metal shutters for panels up to 17.5 kV and insulating shutters up to 24 kV

All UniSec switchgear units are equipped with metallic segregations and are thus in class PM (except unit WBC 24 kV which is PI class).

UniGear ZS1 switchgear also comes under the LSC2B category since the busbar, circuit-breaker and connection compartments are physically and electrically segregated by metallic partitions, thus in class PM.

In the example below, maintenance work can be performed on each of the two transformers while the rest of the switchgear may be kept in service.

The metallic segregations are shown in blue, while the insulating material is in green. The gas-insulated parts are in yellow, while those in air are neutral in colour.

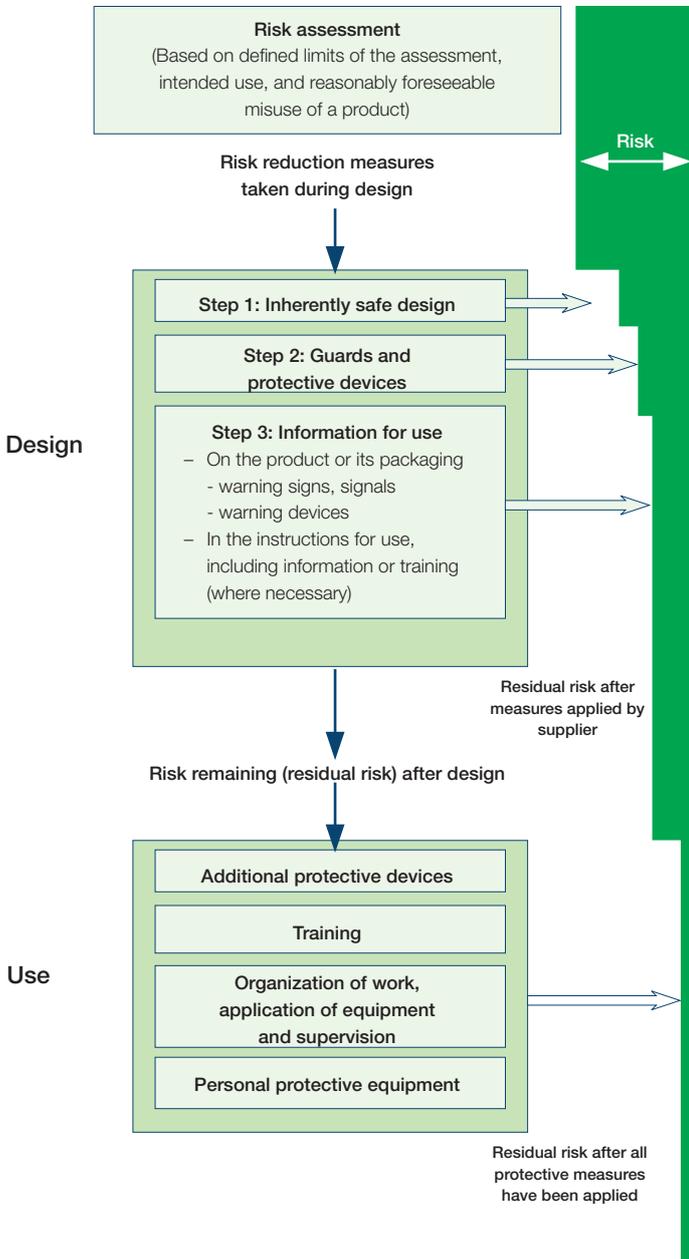


4.6 IAC (Internal Arc Classified) switchgear

Chapter 8 “Guide to the selection of metal-enclosed switchgear and controlgear for service” of standard IEC EN 62271-200 explains that, if the switchgear is installed, used and serviced according to the manufacturer's instructions, the probability of an internal arc occurring is slight, but can obviously not be ignored.

In order to provide an acceptable level of protection when a medium voltage electrical installation is designed and metal-enclosed switchgear/controlgear is chosen, one must bear in mind that internal arc faults may occur owing to the specific context in which the switchgear/controlgear is installed and the operating modes/instructions issued to the personnel. Remember that the persons who transit in the vicinity of a substation are also classified as personnel.

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According to ISO/IEC Guide 51:2014 “Safety aspects – Guidelines for their inclusion in standards”, the risk is a combination of the probability of occurrence of harm and the severity of that harm. Thus, to reduce the risk of internal arc, but not only that, a structured process (described in art. 6 of the ISO/IEC 51 Guide) should be implemented so as to obtain a tolerable level of risk, where the user also plays an active part in its achievement. The risk mitigation process must therefore include:

- an intrinsically safe design;
- protection and surveillance devices;
- detailed information for the user.

An intrinsically safe design is the first and most important step in the risk mitigation process. This is because experience shows that protective measures intrinsic to the product or system remain efficient over time, while the other steps (protections and information) can be removed or disregarded. This is why it is so important to choose intrinsically safe products, designed and made by manufacturers at the cutting-edge as to technological development and application of safety criteria to their products. This applies to all the previously mentioned issues concerning switchgear and controlgear, such as interlocking devices, accessibility levels, etc., but it is especially important when internal arc-proof switchgear is chosen.

This solution also tends to preserve the integrity of things, buildings and activities by reducing the risk of fire outbreaks and the efficacy of one of the ignition sources. Lastly, the efforts made by those manufacturers have also led to a reduction in the size and weight of the switchgear now available with respect to the previous types. This means that less raw materials are used with reduced impact on the environment.

As a guide to choosing the right switchgear with regard to internal arcs, one can affirm that only IAC-classified metal-enclosed switchgear should be used where the risk is considered to be high.

Generally speaking, an internal arc can be caused by different factors, such as: inadequate design, faulty installation, failure of the solid or liquid insulation (defective or missing), faulty operation, corrosion, faulty assembly, temperature rises due to loose connections, when withdrawable parts are racked in or out, ferroresonance, negligent maintenance, ageing under electrical stress, overvoltage, intrusion of small animals through cable input connections, etc.

The energy produced by an internal arc causes violent phenomena such as a sharp increase in internal pressure and temperature, acoustic and visual effects, mechanical stress to the structure of the switchgear, melting and evaporation of various different materials.

These phenomena can lead to serious consequences for personnel present when the fault occurs, such as injuries from ejected solid parts and burns due to the emission of hot gas and incandescent particles.

Thus, even when the metal-enclosed switchgear conforming to the provisions established by standard IEC EN 62271-200 has, in principle, been designed and built to prevent internal arc faults from occurring, the actual standard still defines an internal arc classification, i.e. provides a defined level of protection of persons when the switchgear is in normal service conditions.

The classification must be indicated in the following way:

- Classification: IAC (Internal Arc Classified)
- Type of accessibility: A, B, C
- Classified sides of the enclosures: F, L, R
- Rated values of three-phase arc fault: current [kA] and arcing time [s]
- Rated values of single-phase arc fault (when applicable): current [kA] and arcing time [s]

This designation must be indicated on the rating plate.

The standard defines three types of accessibility to the enclosure of the switchgear in the installation site:

- Accessibility type A: restricted to authorized personnel only.
- Accessibility type B: unrestricted accessibility, including that of the public.
- Accessibility type C: accessibility restricted by installation out of reach and beyond the zone accessible to the public.

For type C, the minimum admissible distance of installation shall be indicated by the manufacturer.

For accessibility types A and B, the sides of the enclosure that comply with internal arc test criteria are identified by the following codes:

- F for the front side
- L for the lateral side
- R for the rear side

The front side must be clearly indicated by the manufacturer. Classified sides do not apply to switchgear with accessibility type C.

Lastly, the rated arc fault currents (I_A , I_{AE}) must be defined for:

- three-phase arc fault current (I_A);
- single-phase arc earth fault current (I_{AE}), when applicable.

When only a three-phase rated characteristic is specified, the pre-defined single-phase rated characteristic is 87% of the three-phase rated characteristic and there is no need to specify it and the rated arc fault time (T_A , T_{AE}). The normal values recommended for the arcing time of a three-phase arc fault (T_A) are 0.1 s, 0.5 s and 1 s.

IAC classification is proved by compliance with the following criteria (consult the standard for further details):

– **Criterion No. 1**

Correctly secured doors and covers do not open.

Deformations are accepted, provided that no part comes as far as the position of the indicators or the walls (whichever is the closest) in every side.

– **Criterion No. 2**

No fragmentation of the enclosure occurs, neither are there projections of small fragments or other parts of the switchgear, up to an individual mass of 60 g.

– **Criterion No. 3**

Arcing does not cause holes in the classified sides up to a height of 2000 mm.

– **Criterion No. 4**

Indicators do not ignite due to the effect of hot gas or incandescent liquids. The indicators are pieces of black cotton fabric placed, on any classified side, on a mounting support at distances that depend on the type of accessibility (see figure).

– **Criterion No. 5**

The enclosure remains connected to its earthing point.



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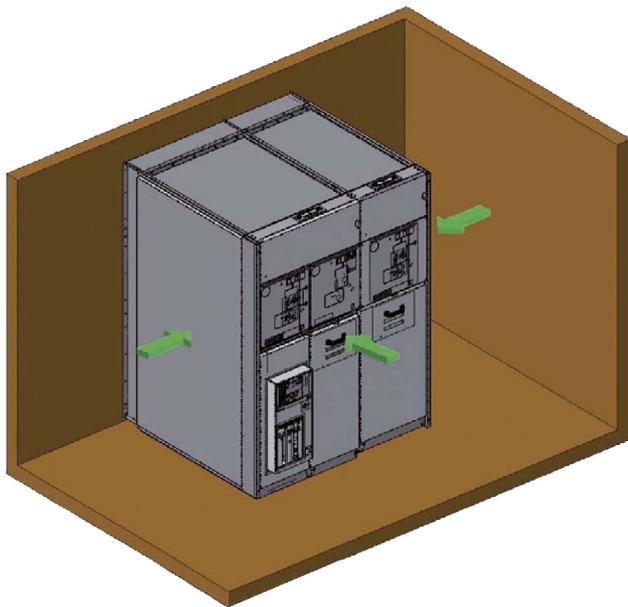
A few examples:

UniSec IAC AFL 12.5 kA 1s switchgear;

The switchgear is protected on three sides (front and lateral) for 12.5 kA arc fault current and 1 s arc fault duration.

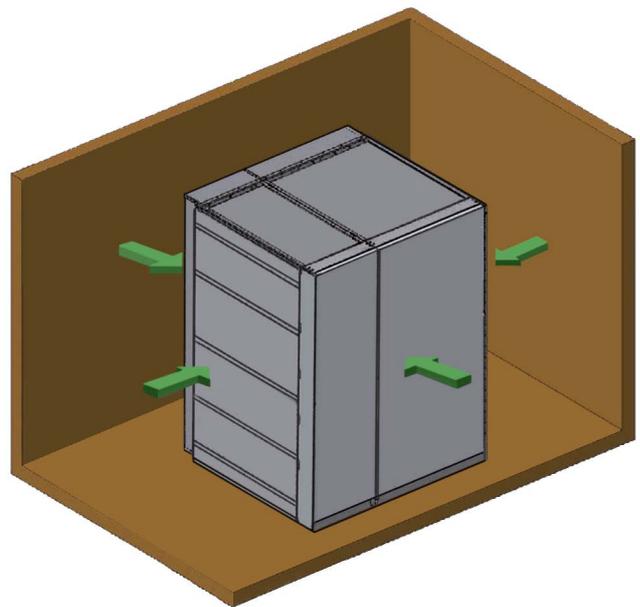
It is available in two versions:

1. Switchgear installed against the wall. In this case, the rear part of the switchgear and the wall form a duct through which gas can pass.
2. Switchgear not completely against the wall. In this case, filters installed in the rear part of the unit cool and lower the pressure of the gas before it is released into the environment. It is clearly forbidden to access the rear part of the switchgear when in service since it is not protected.



UniSec and UniGear IAC AFLR 25 kA 1s switchgear;

The switchgear is protected on four sides (front, lateral and rear) for 25 kA arc fault current and 1 s arc fault duration. Filters installed in each unit cool and lower the pressure of the gas before it is released into the environment.



4.6.1 Additional protection measures

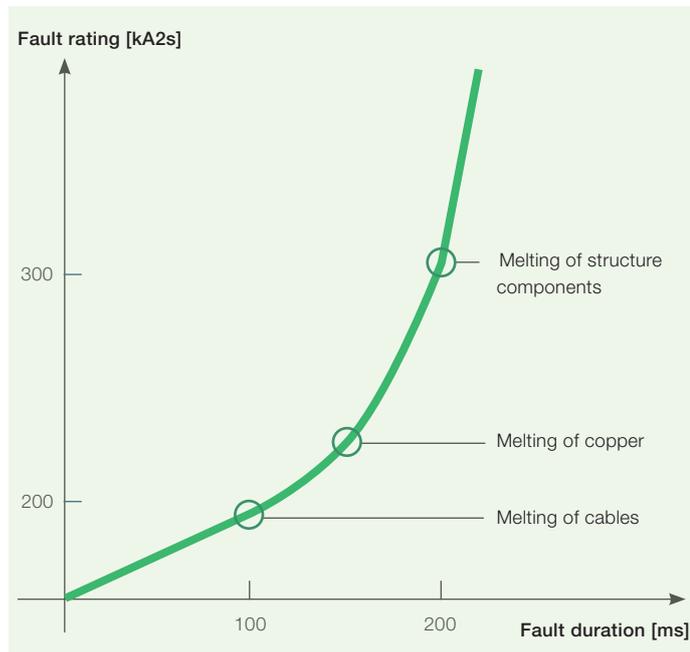
Standard IEC EN 62271-200 (sect. 8.104.3) establishes that other measures may be adopted in addition to the switchgear test, to provide the highest possible level of protection for persons if an internal arc occurs. These measures are aimed at limiting the external consequences of such an event. For example:

- rapid fault clearance times initiated by detectors sensitive to light, pressure or heat, or by a differential busbar protection;
- application of suitable fuses in combination with switching devices to limit the let-through current and fault duration;
- fast elimination of the arc by diverting it to metallic short-circuit by means of fast-sensing and fast-closing devices;
- remote operation instead of operating in front of the switchgear.

ABB has technologically advanced solutions able to cover all the issues mentioned in the standard.

For example, these solutions are able to detect and extinguish the arc by opening the fault feeder circuit-breaker in a selective way. Time is a critical parameter when it comes to reducing the effects of the arc since the energy emitted rapidly increases as time goes by. For example, an arc fault lasting 500 ms can cause serious damage to the installation. If the arc only lasts about 100 ms, the damage is often limited, while if it were to last less than 4 ms, the effects would be negligible.

One must consider that the most important part of fault extinguishing time is due to the break time of the circuit-breaker, while the detector systems act in less than 15 ms. This means that the overall response can take less than 100 ms, so long as the circuit-breaker opens instantly and so long as this circuit-breaker is sufficiently fast.



The result would be to reduce the thermodynamic effects of the fault, thereby limiting damage to the installation and making the event less dangerous.

These systems generally use various types of pressure or flash sensors to very rapidly detect the effects of the internal arc and issue the command that opens the circuit-breaker involved.

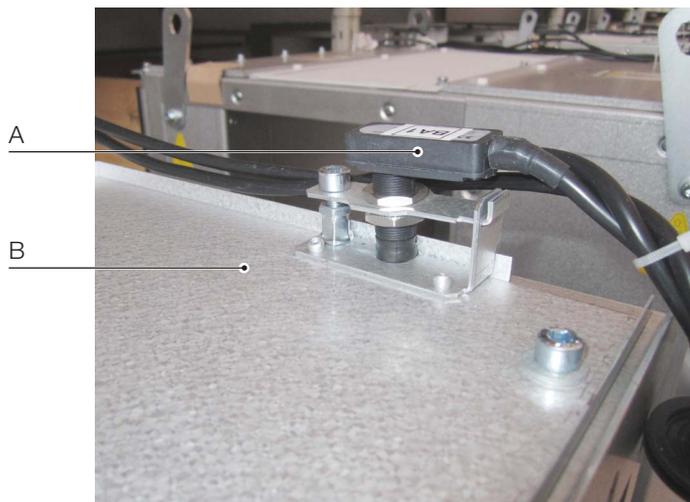
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4.6.2 Pressure detection system

This system consists of pressure sensing devices installed on the top part of the switchgear, near the flaps that exhaust the hot gas generated by the internal arc. The shock wave caused by the pressure generated by the arc propagates very quickly inside the switchgear. This activates the sensing devices, which transmit the opening command to the circuit-breaker that feeds the switchgear.

In this case, ABB proposes the ITH limiter: the pressure sensing device used is sensitive to small, sudden variations and features extremely rapid response times. It consists of contacts mounted on the upper end of each functional unit and possesses characteristics allowing it to be installed directly in the control circuit of the protection circuit-breakers. The contacts immediately generate a fault signal as soon as the overpressure flaps of the unit open owing to an internal arc. Since the contacts of the sensing devices are the maintained-position type, they act as a closing lock for the circuit-breakers they have opened.

The typical trip time of these pressure sensing devices is 15 ms, to which the circuit-breaker break time should be added.



A) ITH limiter
B) steel pressure relief flap

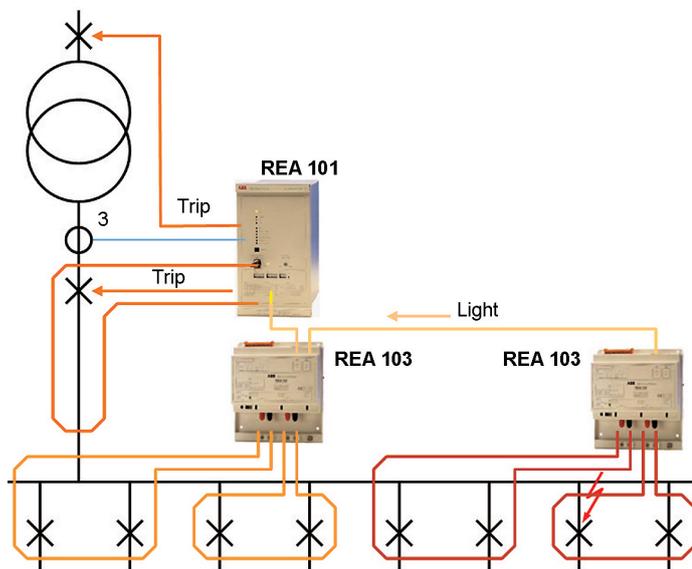
4.6.3 Flash detection system

The first systems for detecting the flash produced by electric arcs date back to the beginning of the '90's. These systems used localized light sensing devices, which were installed in various points of medium voltage compartments to protect against internal arcs. After this, more than ten years later, second-generation systems appeared on the market featuring optical fiber flash detectors able to absorb the light along the entire length of the fibre itself. In this case, ABB proposes the REA system using these new detectors, since they possess undoubtable advantages.



First, they cut down on installation costs since each fiber ring can be up to 60 meters in length and can be routed as required in the compartment to be protected. Secondly, since light absorption is distributed, there is no risk of the detector being obstructed in its “view” of the arc. Lastly, use of the ring configuration makes it very easy to perform autodiagnosis of the detector itself. In terms of safety against false triggering, the system only reads the lower part of the visible spectrum, including the ultraviolet spectrum. Secondly, the system is normally connected to current sensors installed in the main feeder units of the switchgear, which are used to instantly read the line and earth fault currents.

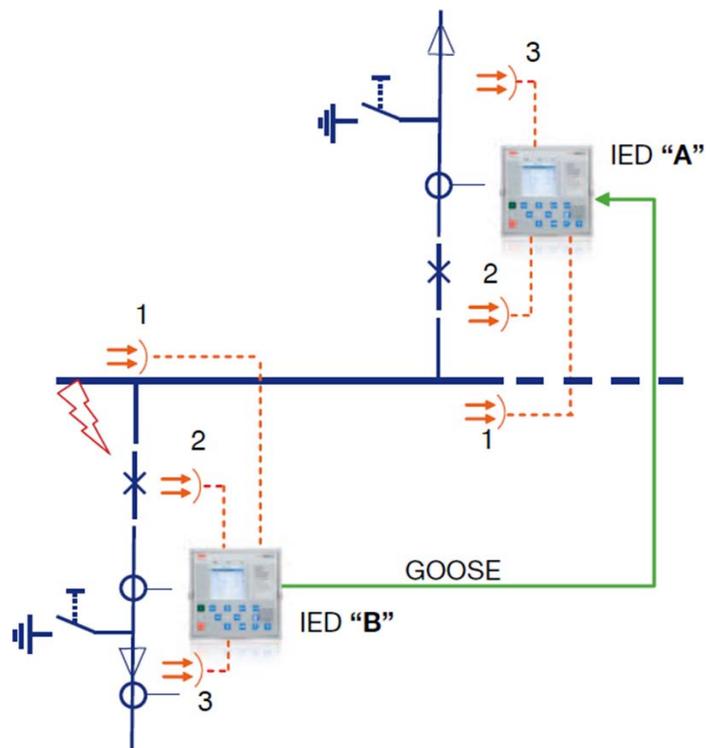
This allows the flash detector reading to be checked for correctness since both arc light and fault current are present during an internal arc fault. The system acts separately from the existing, conventional protection system and therefore does not need to be coordinated with the other protections. If the electrical system is complex with several feeders, selectivity can be obtained by several system units and by differentiating the path of the sensors. The typical tripping time is 2.5 ms, to which the circuit-breaker break time should be added.



4.6.4 Arc detection by IED (Intelligent Electronic Device)

In modern protection systems, certain intelligent devices called IED can be equipped with protection against electric arcs. ABB proposes relays REF615, RET615, REM615 and REF610, which can use lens sensors and create rapid, selective arc protection. Traditionally, protection systems based on cabled interlocks among various functional units are unable to ensure that internal arcs extinguish in time to limit the consequent damage. Modern systems using standard IEC 61850 "Communication networks and systems for power utility automation" and particularly rapid communication

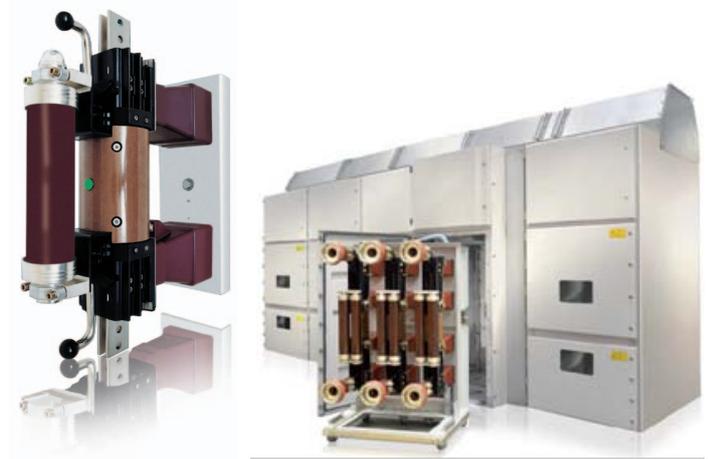
of events via GOOSE (Generic Object Oriented Substation Event), are able to considerably improve the way these interlocks are created and installed. An Ethernet LAN (Local Area Network) that covers the entire substation is used for the purpose and GOOSE communication transits on this support. Use of this system achieves an overall 30% improvement in operating speed compared to a conventional system of interlocks between switchgear relays. The interlocks are simply created by configuring the IEDs, while the autodiagnosis system detects any faults, which are identified immediately and then corrected. Apart from the Ethernet LAN cable, no other cabling is required between the units. Getting back to the internal arc protection issue, each of the units described above can be equipped with three flash detectors, one for each compartment. The IED that detects the arc flash transmits a GOOSE message, while the receiving IED of the feeder unit rapidly opens the relative circuit-breaker. The typical tripping time is 10 ms, to which the circuit-breaker break time should be added.



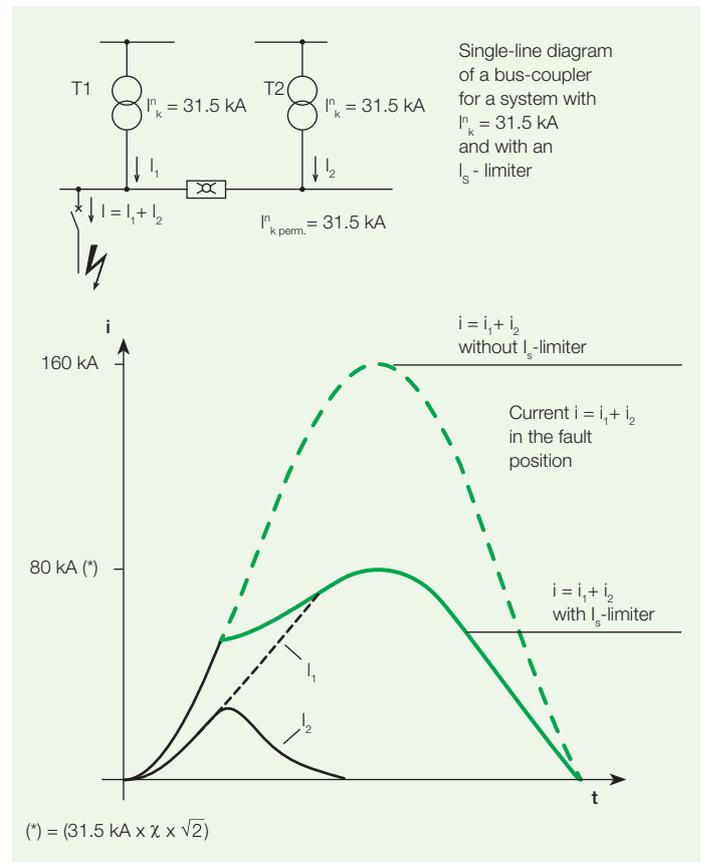
4. Electrical safety in medium voltage switchgear

4.6.5 Current limiting devices

Fast breaking devices were developed during the second half of the '50's and are able to drastically limit short-circuit currents and their effects on the components of an electrical installation. These devices can detect and interrupt short-circuit current at the very first rise by acting within a few milliseconds. This device basically consists of a part that supports the actual limiter insert, the protection current transformer and the electronic measuring and tripping device. If a fault occurs, the electronic device transmits an impulse via a transformer (in the supporting isolator) to the explosive charge in the insert. Following a small, controlled explosion, the main conductor opens and the current commutates through the parallel high rupturing capacity fuse, blowing of which first limits and then interrupts the current the first time it crosses zero. The current is constantly monitored by the external measuring system, which measures the derivative of current and is thus able to rapidly decide whether to trip the current limiter or not. In normal operating conditions, the parallel fuse and conductor combination allows losses to be kept to the minimum. In short, compared to other limiting devices, this solution keeps service losses down and efficiently limits short-circuit current on the load side. ABB has developed a device of this type called Is-Limiter. This device, which can be supplied in its own panel on a withdrawable truck, covers a wide range of voltage levels from 750 V to 36 kV and currents from 1250 to 5000 A. Is-Limiter is designed for use in a considerable variety of plant situations, the most interesting of which is installation as bus-coupler between two busbar systems supplied by two different sources. If the fault involves one of the two sources, Is-Limiter trips at the very first rise before the current is able to reach high levels. The voltage in the part of the system not affected by the fault only drops for fractions of a millisecond at most. Consequently, all the loads continue to be supplied. As can be seen in the example, the device trips so fast that there is practically no contribution from the second supply source. Thus the switchgear can be sized for a lower short-current value.



By drastically limiting the let-through fault current and the duration of the fault itself, Is-Limiter falls within the additional protective measures indicated by the standard for limiting the effects of an internal arc.

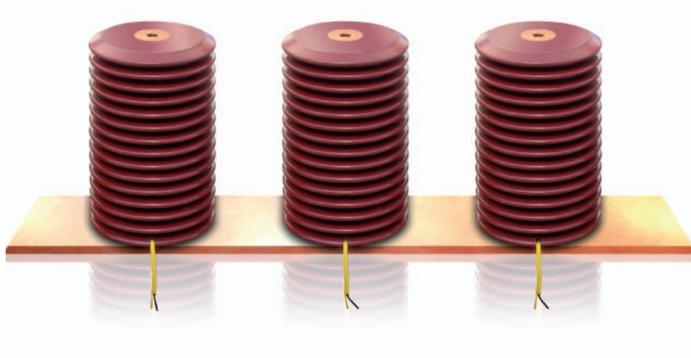
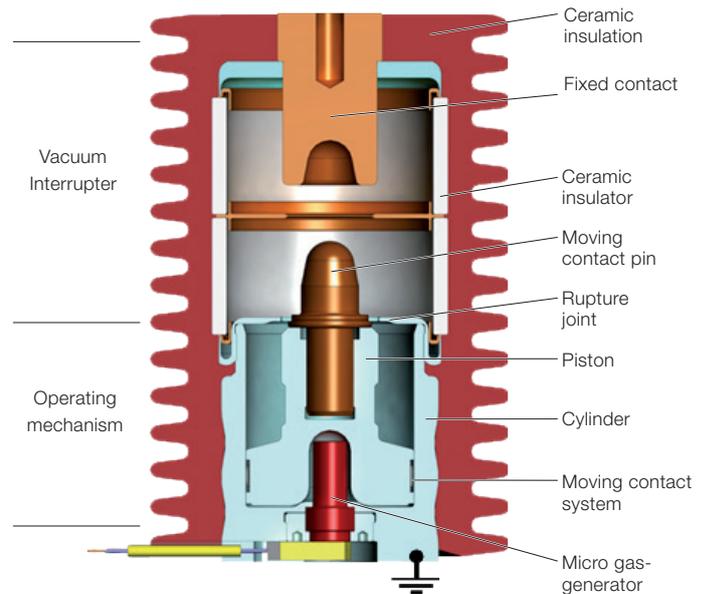


4.6.6 Ultra-rapid earthing system

Among additional protective measures, an ultra-rapid earthing system is the fastest and most effective way to reduce the effects of an arc inside switchgear. This system includes the positive characteristics of the systems described previously, but is also able to strongly limit the impact of the energy released by the arc in a very simple way, thus with a high cost/benefits ratio. The arc only takes a few milliseconds to extinguish and this allows the majority of the damages caused by the thermal and mechanical effects of the fault to be prevented. This sort of system provides evident advantages:

- drastic reduction in repair costs since the unit affected by the fault need not normally be replaced
 - increased system and process availability since all that needs to be done is to eliminate the cause of the fault to restore service rapidly
 - decidedly increased operator safety during normal use.
- In this case, ABB proposes the UFES (Ultra Fast Earthing Switch) system. UFES consists of a primary switching device and an electronic device.

The switching device is embedded in epoxy resin and contains a moving contact pin set in motion at high speed by a magnetic repulsion effect generated by a Thompson coil.



These single-phase devices are typically installed in the incoming unit of each half-busbar, in the case of two incoming feeders where the installation is controlled by a normally open bus coupler, in an empty compartment or in a dedicated kit to install on top of the incoming unit, and can also be assembled in existing switchgear after small modifications have been made by the Service staff.

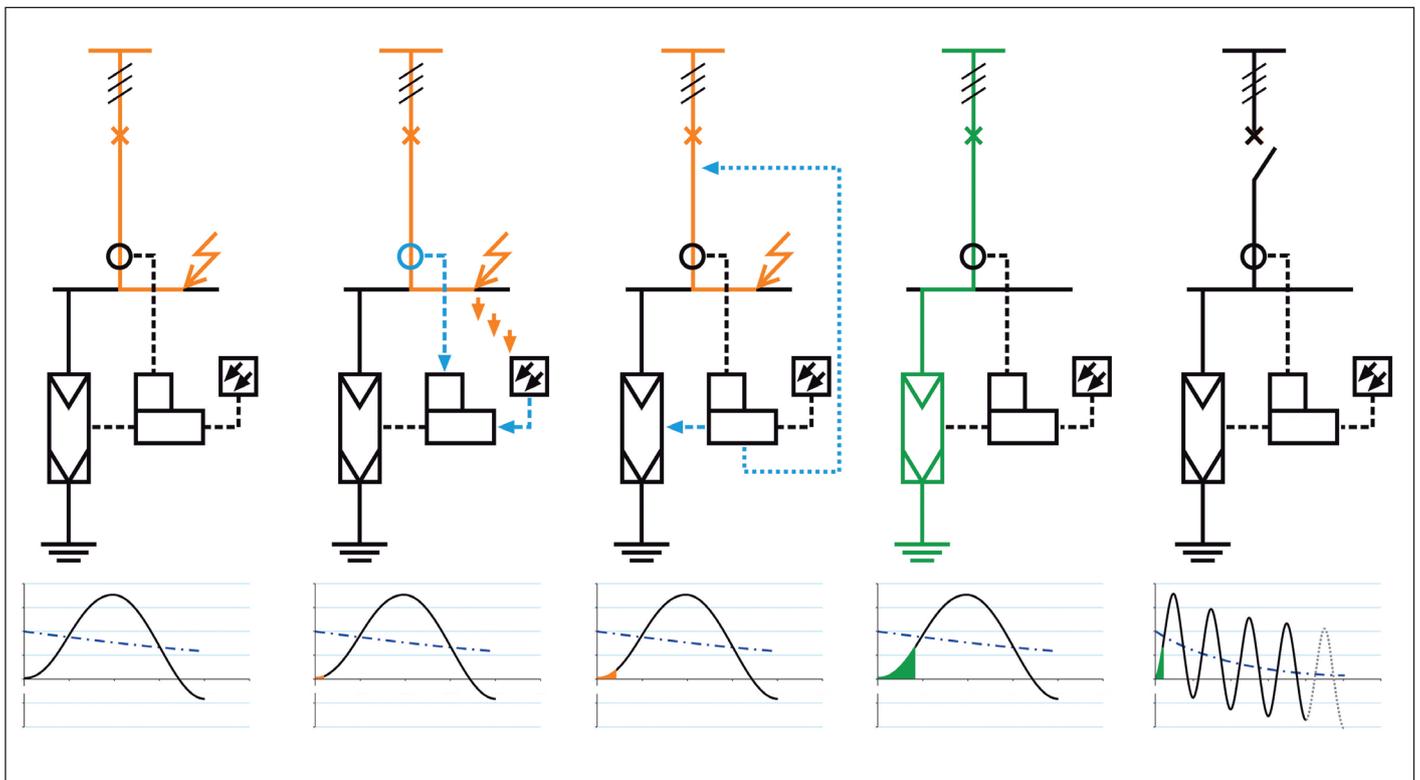


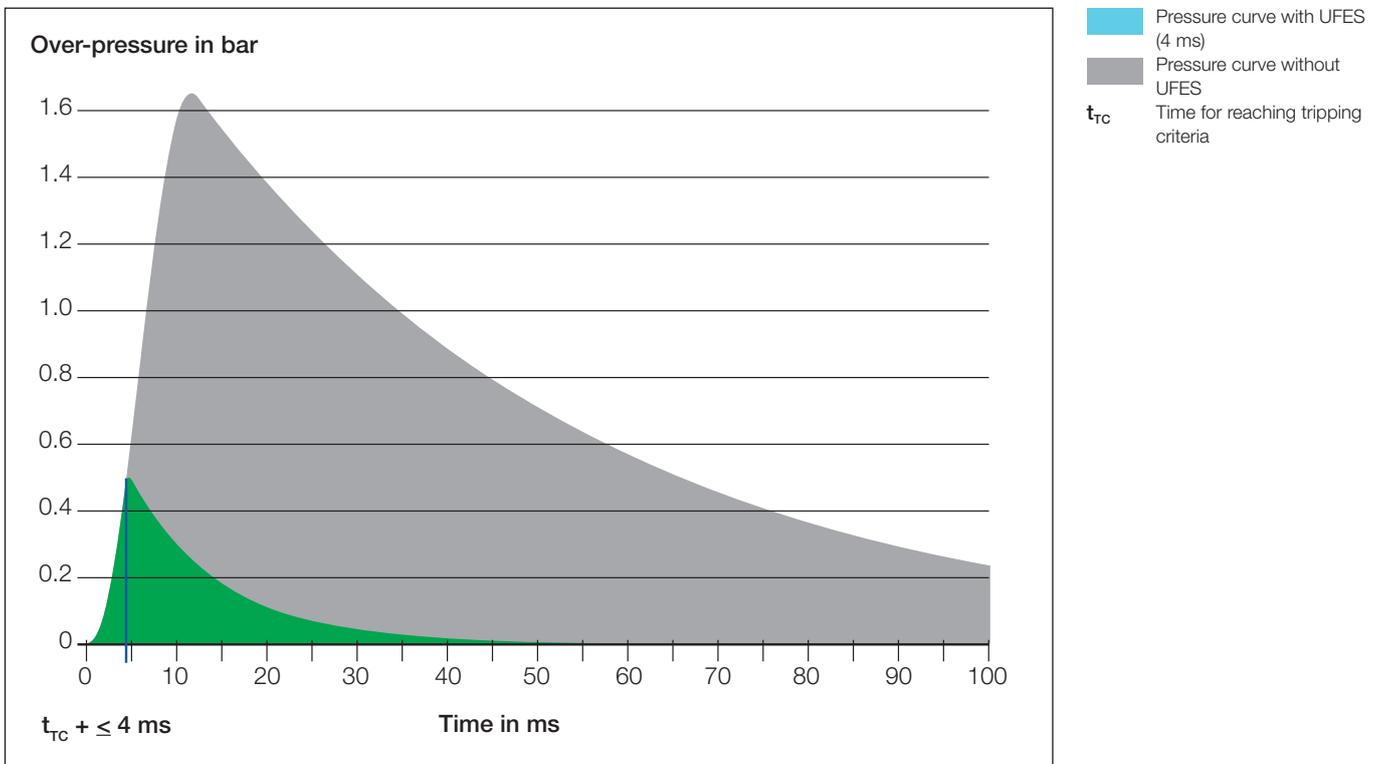
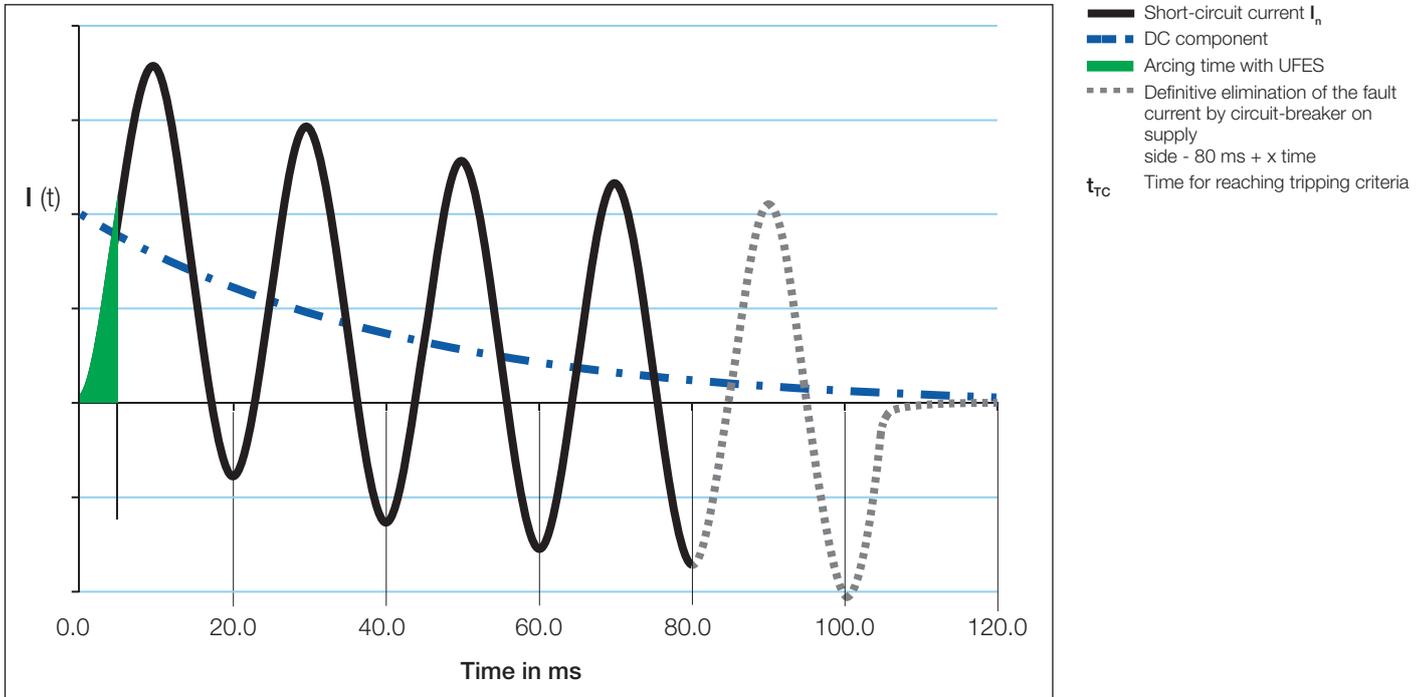
4. Electrical safety in medium voltage switchgear

These devices operate in the following way: flash detectors in the compartments that need to be protected, send a signal to the monitoring unit to indicate that an arc is present. The monitoring unit transmits a closing command to the three fast operating mechanisms, which establish a three-phase dead-short to earth. The impedance of the dead-short is so low that all the current commutates to the new fault, causing

the arc to immediately extinguish. After this, the fault current is interrupted by the circuit-breaker of the incoming unit. Typically, the arc takes 4 ms to extinguish.

As can be seen in the graphs on the next page, the energy (green area) and pressure (light blue area) are considerably less than they would be without UFES.





It is estimated that the energy released is less than 1% of the energy released by the arc during a 1-second internal arc withstand test. Sometimes, not even the pressure and hot gas relief flap opens under these conditions.

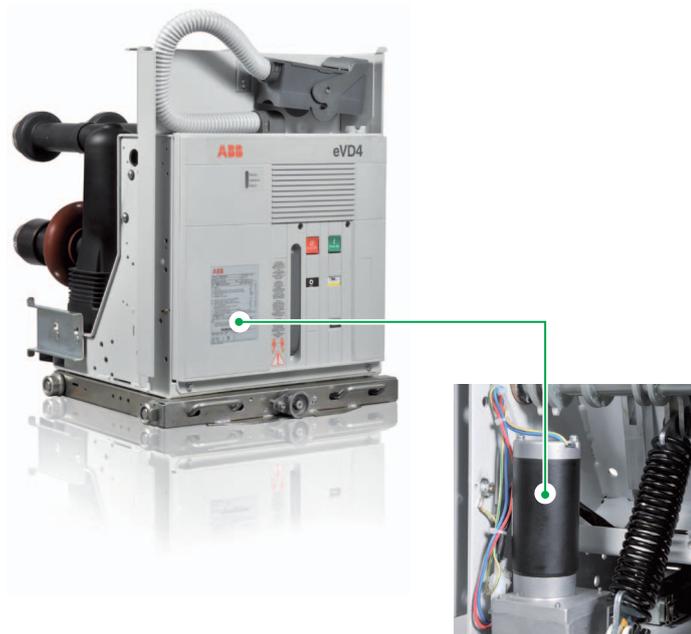
This solution is therefore suitable for enhancing the safety of existing, non-IAC classified switchgear.

4. Electrical safety in medium voltage switchgear

4.6.7 Remote operation

The standard generically suggests remote control instead of operating in front of the switchgear. This paves the way to a vast array of solutions ranging from remote racking-in/out of circuit-breakers to remote supervision and control systems.

Remote racking-in/out of circuit-breakers



This function allows a certain distance to be maintained between the operator and the energy generated by an internal arc if a fault occurs in the switchgear. Operations on the circuit-breakers can then be performed in enhanced safety conditions. Racking-in/out a circuit-breaker with respect to the connected position are high-risk operations. ABB vacuum circuit-breakers can be equipped with an integrated motor-operated racking-in/out system. New switchgear can be outfitted with this device at the start, otherwise it can be installed at a later date by the Service staff.

Racking-in and out in older switchgear is performed by directly accessing the circuit-breaker with the door open. In such conditions, a failure or faulty operation when racking-in and out can lead to dramatic consequences for the operators. Creating controlled operating conditions with the circuit-breaker compartment door closed is therefore important for safety, especially when old circuit-breakers are involved since they are more liable to mechanical faults.



ABB Service proposes a closed-door motor-operated racking-in/out solution for old circuit-breaker retrofits that functions by remote control.

Working when one is sure that no voltage is present is a further safety condition, regardless of any errors in communication with other operators or failures that may occur. This can be achieved by using a local voltage display. ABB has developed a product of this type based on the use of liquid crystal displays (LCD) which are sensitive to the alternating current field and do not require any auxiliary supply. The product is called VisiVolt and can also be installed in existing systems if voltage indicators were not provisioned when the installation was designed.



Supervision and control systems



These systems improve safety in many different ways: for instance, apparatus, circuit-breakers, motor-operated disconnectors and contactors can be operated by remote control from a control room, thereby minimizing the risk of accidents for personnel. In addition, a series of interlocks can be planned by considering all possible plant situations, something that is very complicated to do by conventional methods. For example, such systems can take account of the different servicing situations, avoiding incorrect operations when operators are present in the installation.

They can also keep all staff members informed by locally transmitting maintenance information to the technicians, etc. Safety interlocks in switchgear and functional units are obviously not replaced but integrated, thanks to an overall view of the functionality of the entire electrical installation. Different clearance levels can be defined for different actions, depending on their critical nature and their type of impact on the installation. For example, a motor can be started by a simple operator, while changes to the configuration of the installation would require a superior level of competence and authorization.

4. Electrical safety in medium voltage switchgear

ABB offers tried-and-tested solutions in this particular field, such as the MicroSCADA systems, which ensure perfect integration with the various IED devices that protect and monitor the installation.

Control center



MicroSCADA Pro system server and workstation



Interbay bus IEC 61850 (ring configuration)



Remote communication IEC 101/IEC 104/DNP 3.0

MicroSCADA Pro communication gateway

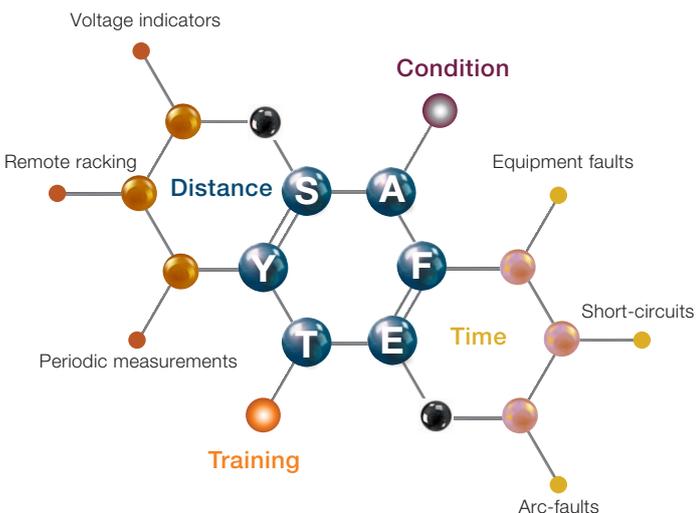




5. Maintenance

As described in the chapter dedicated to laws and regulations, Legislative Decree d.lgs. 81/08 “Electrical plant and equipment”, article 80 “Employer’s obligations” establishes that, among other commitments, employers are obliged to provide operation and maintenance procedures able to ensure that the safety level achieved by implementing the measures adopted remains unaltered over time. As time goes by, negligent maintenance leads to the hazardous conditions that both the technical standards and manufacturers endeavour to limit by introducing rules and innovations when their products are designed and built. Maintenance is a vast subject and may range from assessments of the conditions of equipment and the likelihood of risk, to installation of advanced monitoring systems for condition-based maintenance. It may also include many other services, like training for site operators, on-call support in emergency situations, etc. The goal is always to guarantee the utmost reliability of the electrical installation over time.

With reference to the diagram below, we have already seen how the operator’s distance from the switchgear, reducing the duration of the fault and, thus, of the effects produced by an internal arc, contribute considerably towards reducing the risk of accidents. The other two issues to consider are awareness of the real conditions of the installation and staff training. Knowing the real conditions of one’s installation means



assessing the state of the switchgear/controlgear so as to establish a risk profile based on these conditions and their importance in the electrical network. Priority action areas can be defined on the basis of this analysis for the purpose of mitigating existing hazards and avoiding effective risk situations. The possible action areas include:

- risk monitoring and risk reduction programs to maximize reliability and reduce operator exposure to the minimum;
- switchgear/controlgear upgrading and retrofitting to enhance their intrinsic safety: maintenance activities based on state-of-the-art technologies, faster opening-closing cycles and troubleshooting procedures;
- diagnostic tests able to assess the quality of the connections and the effects of pollutants, mechanical failures and defective apparatus.

When it comes to staff training and given that faults are very often caused by human error, it is evident that properly trained personnel are essential if correctly performed operations and, thus, operator safety are to be guaranteed.

This issue includes true training, as well as the development of procedures and technical consultancy services:

- technical and engineering training services allow the operators to become more familiar with the switchgear and systems, thereby ensuring that they are operated in the right way;
- assessment of the risks associated with internal arcs helps to establish the type of personal protective equipment (PPE) that operators are required to use in the vicinity of potentially hazardous areas. They also help to define switchgear better able to limit and extinguish internal arc faults;
- technical consultancy services provide documentation about over-voltage and overcurrent due to transients associated with switchgear operation, as well as protection settings and coordination plus integration of relays and protection apparatus to ensure that the system functions as required when stressed by faults.

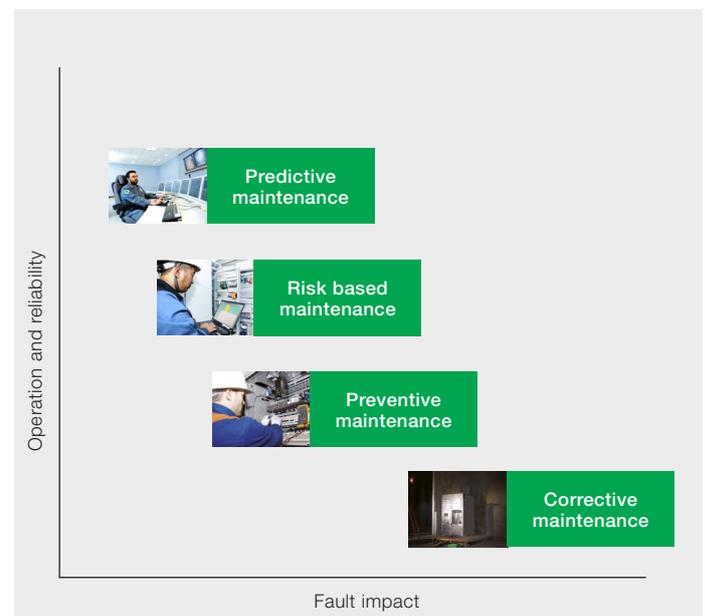
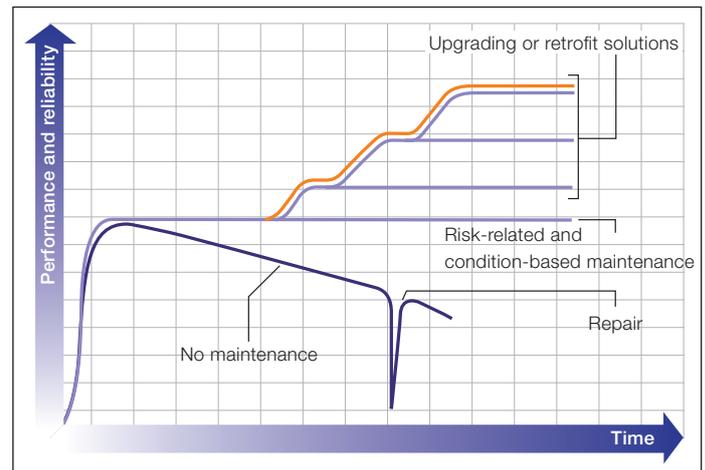
ABB Service offers all these services in the Power Care package, which can be customized to suit the customers' real requirements. The ABB Power Care framework is based on a matrix of services that cover five macro areas (1- Skills development services, 2- Emergency maintenance services, 3- Diagnosis and condition assessment services, 4- Self-maintenance services, 5- Delivered maintenance services) and four service levels (entry level, level 1, level 2, level 3). The customer can choose the services he needs.

When it comes to the effective maintenance of an electrical installation, the customer can choose from various different strategies. Obviously, failure to provide for maintenance is not a viable option since in the long run, it could expose the operators to the risk of accidents and the installation to damage. Other possible strategies are scheduled maintenance, preventive maintenance based on risk assessment and, lastly, maintenance based on continuous monitoring of the effective state of the installation. Continuous upgrading of the installation on the basis of technical developments in the sector would be an optimum solution worth considering.

Scheduled maintenance is performed at planned regular intervals or according to criteria able to reduce the risk of faults and progressive deterioration of the installation. Maintenance work is generally organized on the basis of planned outage (putting out of service).

Preventive maintenance is based on periodic analyses, measurements and tests performed in order to obtain information about the state of the installation, also considering the environmental, operating and process conditions of the switchgear/controlgear. The purpose is to obtain an overview of the state of the installation and an updated risk assessment allowing the most appropriate maintenance schedule to be defined. All switchgear/controlgear showing abnormal values can then be repaired or replaced, thus lengthening the useful life of the installation while ensuring high-level safety, reliability and efficiency.

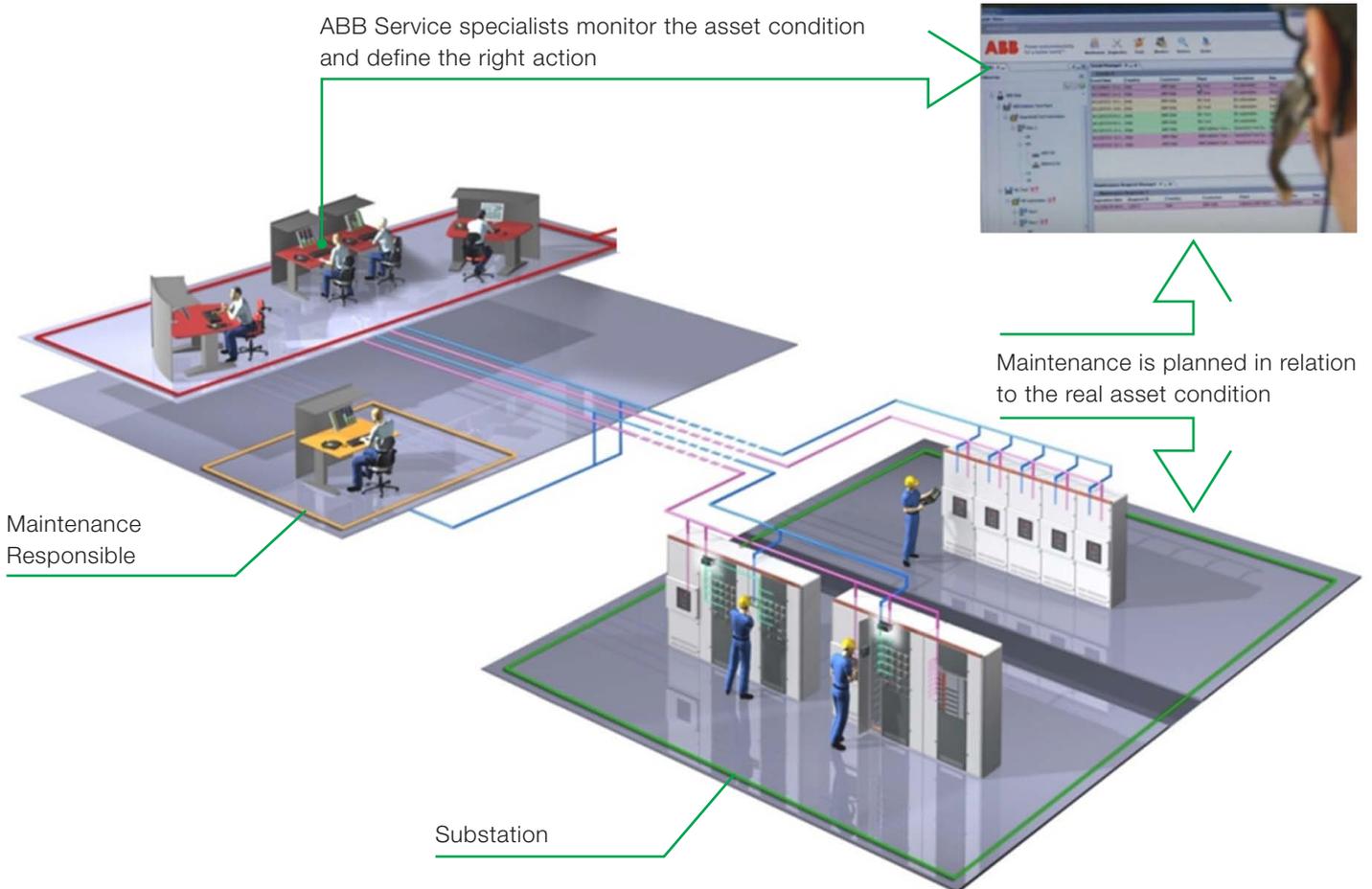
Maintenance based on continuous monitoring of the installation is certainly the most advanced type because it does not merely consider the real conditions of the switchgear/controlgear, but also allows the effectiveness of the corrective actions to be assessed. To achieve this, the operating parameters of the main components in the installation must be defined, continually monitored and compared with reference values. Maintenance is then performed by providing prognostic reports to indicate when the likelihood of fault occurrence is increasing. In the long-term, this strategy drastically cuts down on maintenance costs, while reducing the risk of faults and optimizing the use of available resources.



5. Maintenance

ABB proposes MyRemoteCare and MySiteCare for this final application. MyRemoteCare can store diagnostic information about individual devices and uses it to generate reports and alarm signals. Log data and trend analyses allow deviations from standard behaviour over time to be determined. Not only does on-line monitoring enable ABB Service engineers to analyse the diagnostic data of the circuit-breakers, but also of low and medium voltage devices and transformers, predict faults, assess causes and undertake maintenance procedures at the right time.

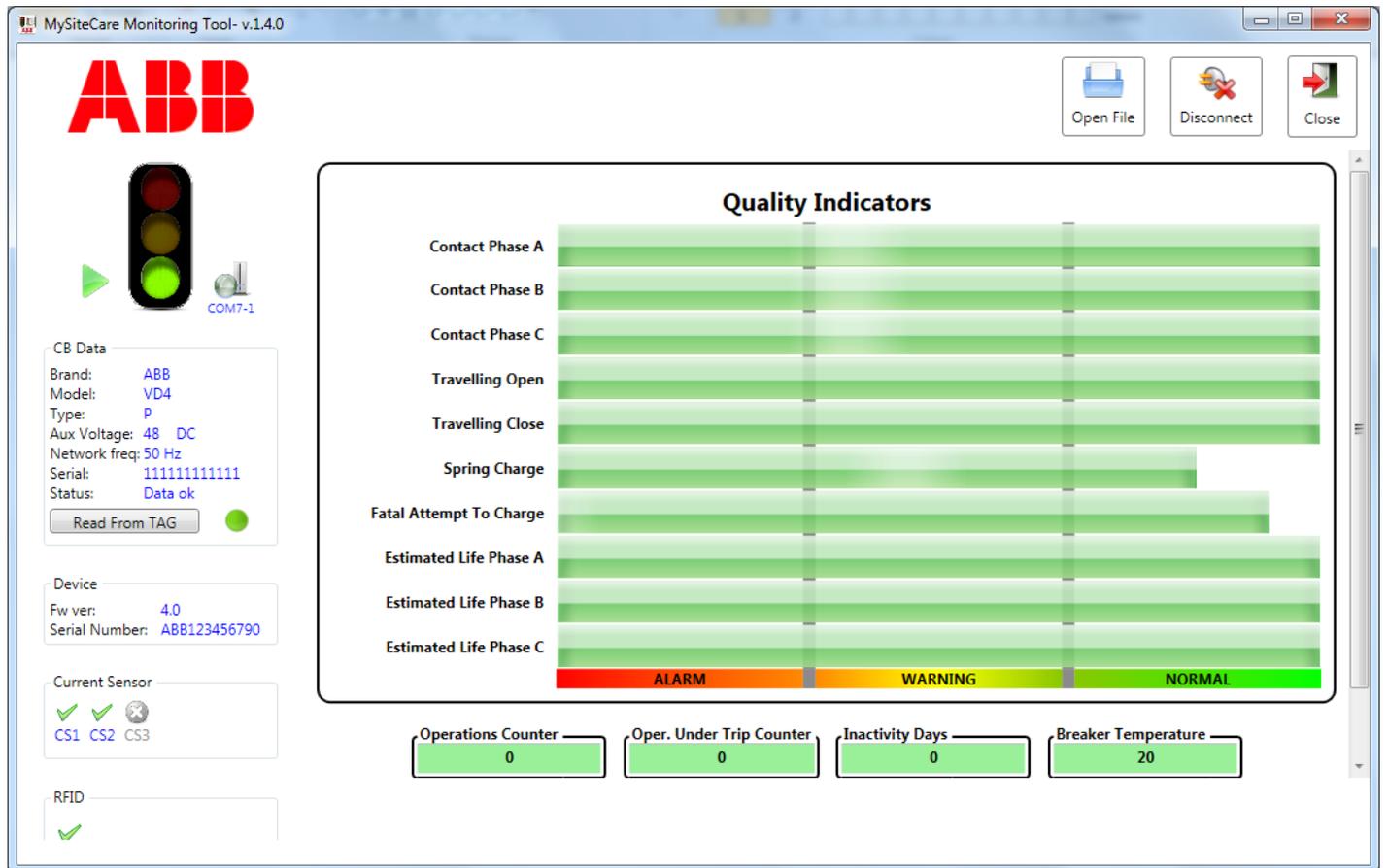
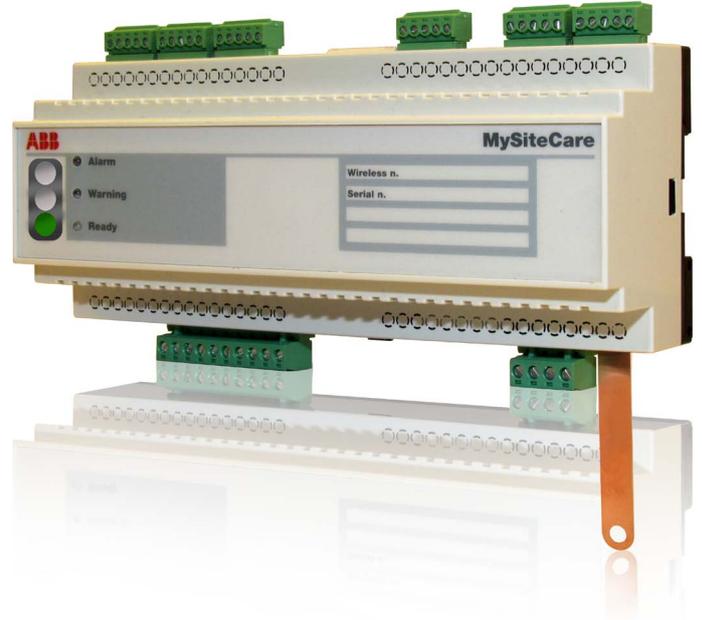
Maintenance managers can check out the tasks planned and performed by the ABB engineers by consulting the MyRemoteCare portal. The system acquires diagnostic information from various sources: IED, smart circuit-breakers, sensors and integrated diagnostic systems. When these devices are not available, ABB can provide MySiteCare, i.e. a universal circuit-breaker diagnostic unit.



MySiteCare is a monitoring and diagnostic device that acquires information from circuit-breakers and processes it into diagnostic data for the purpose of determining the operating conditions and allowing maintenance to be planned. It can acquire the following information:

- mechanical data: opening and closing times, spring loading times, slipping and failed spring loading attempts, number of operations, idle time;
- environmental data, such as the temperatures in the functional unit compartments;
- diagnostic data, such as remaining life estimations and contact wear.

The device processes predictive algorithms on the basis of these data and provides indications about the mechanical, electrical and functional conditions of the circuit-breaker.



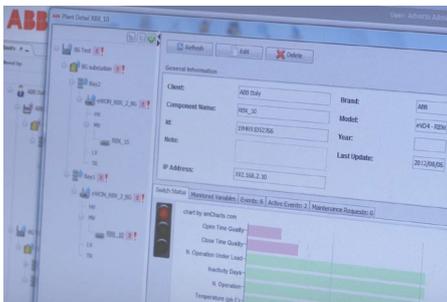
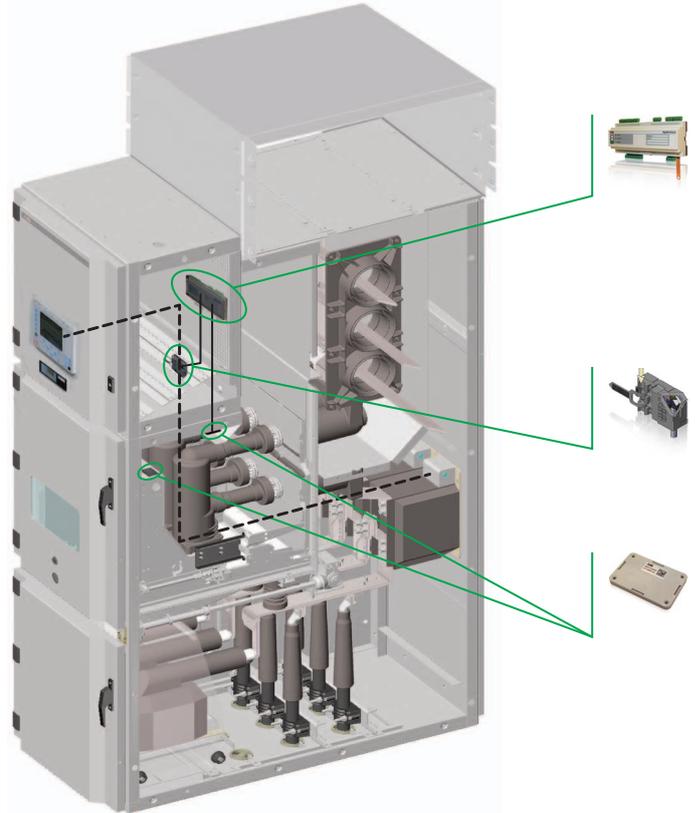
5. Maintenance

MySiteCare has a user-friendly interface that displays the circuit-breaker state by means of a traffic light, where the colour indicates how serious the problem is and the probability of failure, its negative impact on availability or, worse still, on safety.

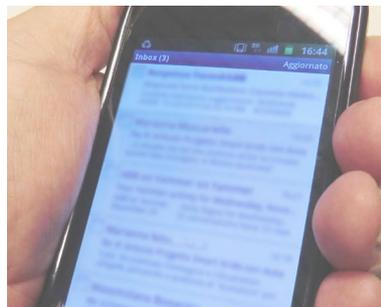
No changes need be made to the switchgear, circuit-breaker or protection relay. The components that need to be installed include the central processing unit, the current sensor and wireless identification device (RDIF), which stores the circuit-breaker data and transmits them to the central unit. The predictive algorithms are configured by ABB engineers at the time of installation.

The information processed by each MySiteCare device is transmitted via RS485 to a hub containing a SIM card for communication to the ABB Data center, via a mobile phone network (2g/3G ..) and channel dedicated to safety.

If there are no important events (which would be notified immediately), the state of the installation is updated every 24 hours, while the state of the connections to the installation are analysed to assess data quality and availability. ABB engineers can access the portal via the Internet so as to consult the diagnostic data and provide the required support.



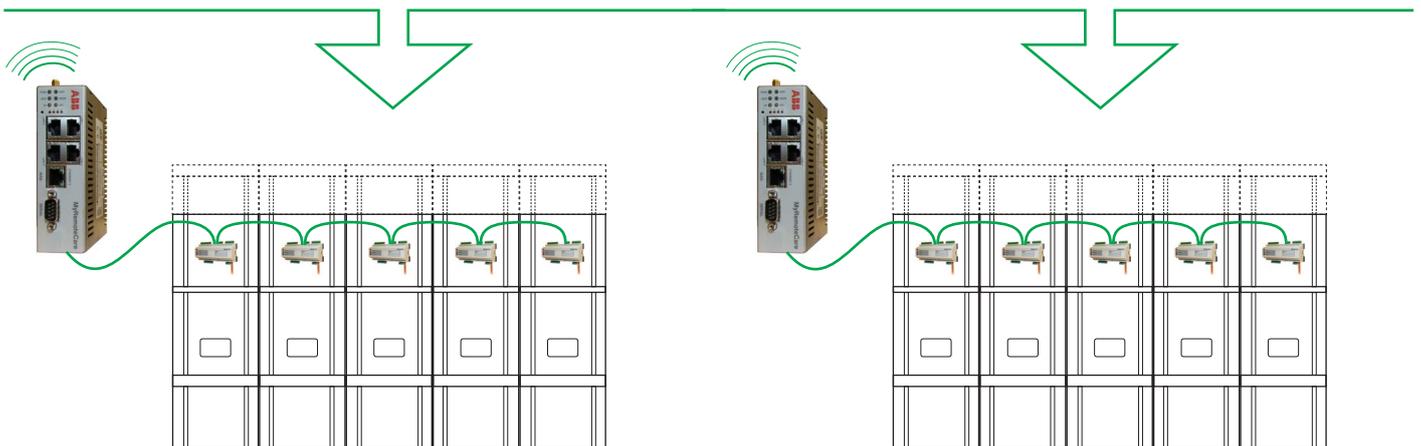
Information accessed via the Internet



Alert via email



Brief periodic reports



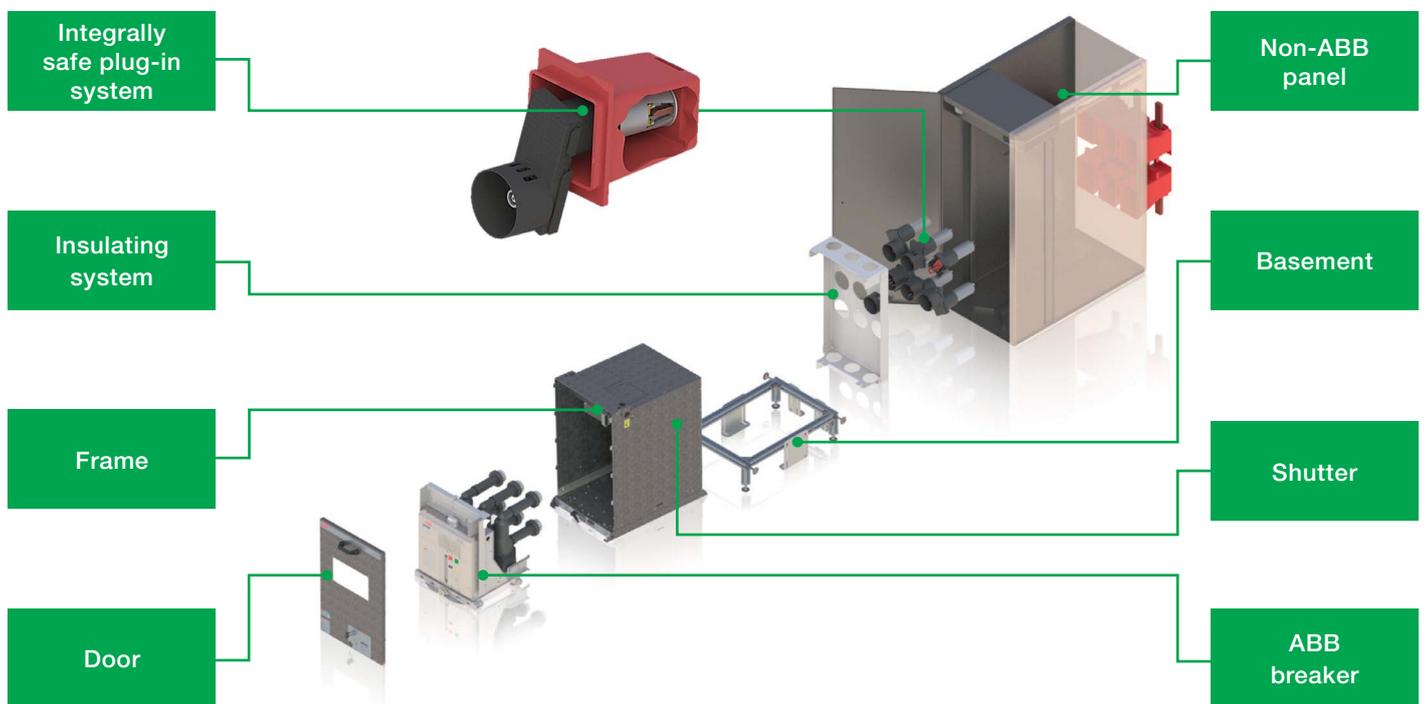
Transmission of diagnostic information from installation to MyRemoteCare

Lastly, switchgear/controlgear upgrading and retrofitting are further solutions to the problem of maintenance since they are able to adapt installations to state-of-the-art technology and safety levels.

After thorough analysis of the state of the switchgear, complete replacement may be the most convenient option, rather than resorting to routine maintenance.

For example, old circuit-breakers featuring obsolete technology (e.g. air or minimum oil circuit-breakers) can be replaced by modern SF6 or vacuum circuit-breakers for which solutions able to enhance operator safety have been implemented.

In this case, the solution proposed by ABB is called OneFit:



The new circuit-breaker is mechanically and electrically adapted following on-site assessment of the existing switchgear performed by expert engineers. The result is not only an improvement in performance (typical of new apparatus), but also and above all in safety thanks to solutions such as interlocks between circuit-breaker and door, remote controls, racking-in/out with the door closed and everything that modern technology provides as to protection and monitoring functions.

6. Conclusions

Law No. 186 of 1 March 1968 established that electric and electronic materials, apparatus, machinery, installations and systems designed in compliance with the standards issued by the Italian Electrotechnical Committee are considered to be built in accordance with the best working practices. Establishing and requesting, right from the initial design phase, that the minimum requirements envisaged by the standards in terms of safety be applied to one's installation means starting out in the best of ways by reducing the risk of accidents. Relying on manufacturers with proven ability to comply with the standards, design, test and install innovative products and propose additional solutions that reduce the degree of risk to a further extent is the next essential step. Lastly, plant maintenance must be performed as required by law. What better than an all-round approach to the issue together with a reliable and proactive partner.



Contact us

ABB S.p.A.
ABB SACE Division
Medium Voltage Products
Via Friuli, 4
I-24044 Dalmine
Tel.: +39 035 6952 111
Fax: +39 035 6952 874
e-mail: info.mv@it.abb.com

www.abb.com

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